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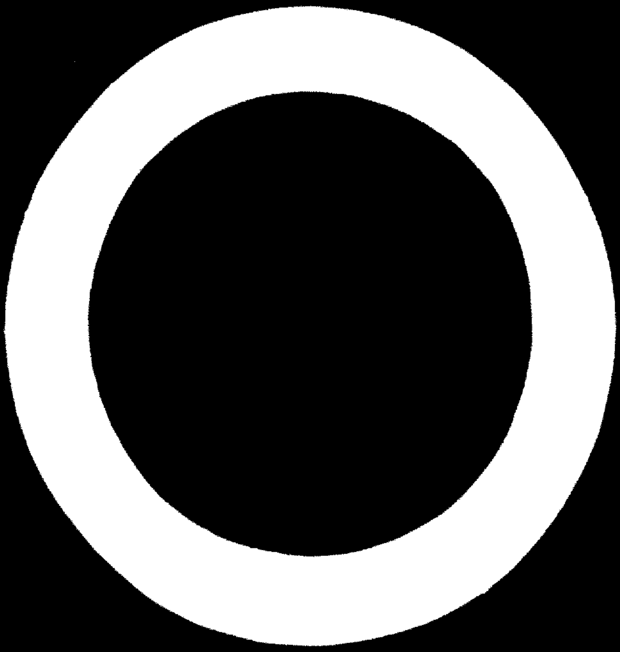
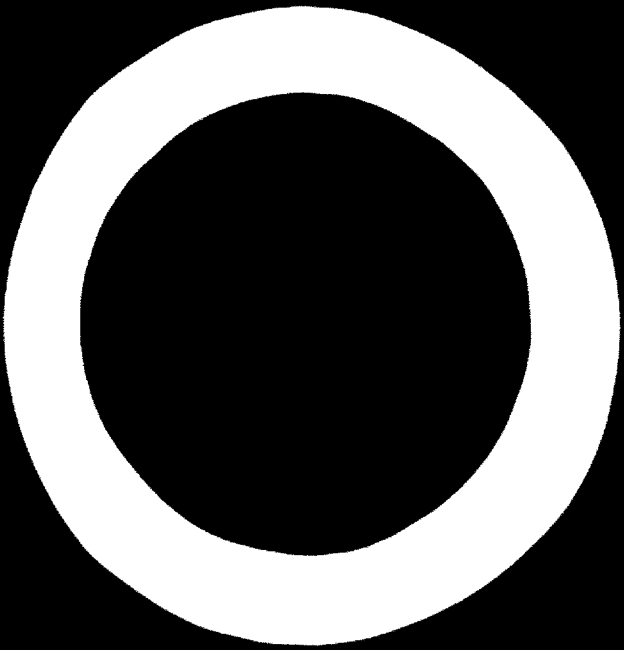
TRAINING FOR INDUSTRY SERIES NO. 3

THE ŁÓDŹ TEXTILE SEMINARS

8. Plant and power engineering

UNITED NATIONS





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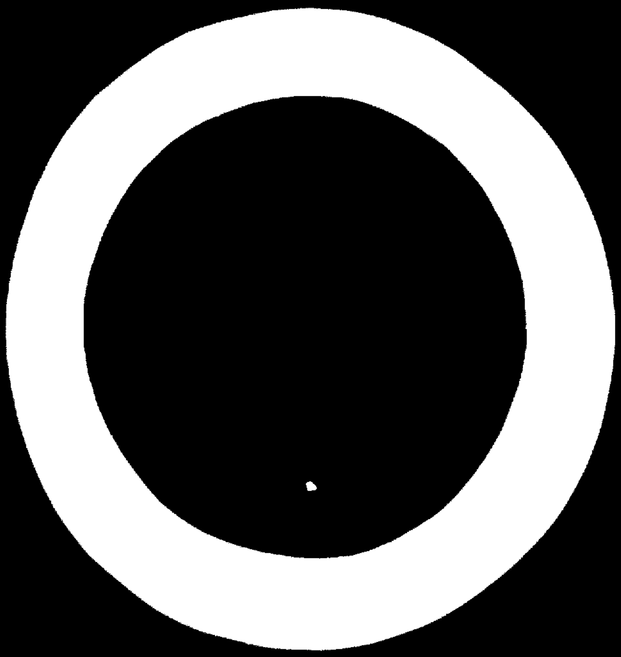

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

TRAINING FOR INDUSTRY SERIES No. 3

THE ŁÓDŹ TEXTILE SEMINARS

8. Plant and power engineering

UNITED NATIONS
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FOREWORD

This publication is the eighth of a series devoted to textile engineering and closely related fields. It is part of the Training for Industry Series published by the United Nations Industrial Development Organization (UNIDO).

Rapid world-wide increases in population and industrialization are reflected in the textile and allied industries. In any ranking of human needs, fibres and textiles for clothing and industrial purposes are second only to foodstuffs. The continuing quantitative and qualitative changes in textile production require the broadest and most complete dissemination of information in this important area.

The purpose of the present series is to make available to the developing countries the most recent scientific and technical information in order to help them to establish textile industries or to improve the effectiveness and economic viability of existing textile industries that are still in the earlier stages of economic development.

At the suggestion of UNIDO, with the support of the authorities of the Polish People's Republic, a post-graduate in-plant training course in textile industries was held in Łódź from May through September 1967. The course was repeated from May through October 1968, and its content was modified and up-dated on the basis of experience and new information. It was repeated again in 1969 and it is planned to continue this programme, up-dating its subject matter and improving its usefulness to the textile industries of the developing countries. It is on these courses that the present series is based.

The courses were organized by the Textile Research Institute in Łódź with the object of training a group of already highly qualified specialists in all branches of industry relating to textiles. Under normal conditions, such training would require work in mills and in research and development over a period of several years.

The courses give the participants an opportunity to become acquainted and to do actual work in conjunction with some of Poland's leading research centres and industrial enterprises, and to discuss with experts problems connected with techniques, technology, economics, organization and research in the field of textiles. In organizing the courses, the Textile Research Institute endeavours to co-ordinate the content of theoretical lectures, technical discussions and practical studies in laboratories and mills, covering all the fundamental problems of textile industries.

The main object of the seminars is to adapt the broad range of problems presented by Polish specialists to the direct needs of the developing countries. Lectures by the research workers of the Institute formed the core of the programme. The lectures do not review or repeat the basic problems usually studied at technical colleges and high schools in the course of normal vocational training; rather, they deal with subjects most often of concern to the management and technical staff of a textile enterprise.

The lectures, as presented in this series, have been grouped in eight parts: textile fibres; spinning; knitting; weaving and associated processes; non-conventional methods of fabric production; textile finishing; testing and quality control; and plant and power engineering.

It is hoped that the experience gained from these courses, as presented in this series, will contribute to the improvement of textile industries everywhere, and particularly in the developing countries.

The views and opinions expressed in this publication are those of the individual authors and do not necessarily reflect the views of the secretariat of UNIDO.

CONTENTS

EXPLANATORY NOTES

References are indicated in parenthesis in the text, by name of author and year of publication. The full references are listed, alphabetically by author, at the end of each article.

References to "tons" indicate metric tons and to "dollars" ($), United States dollars, unless otherwise stated.

The following abbreviations have been used:

cpi means "courses per inch".

Denier (den) is the weight in grams of 9,000 metres of yarn.

gg is "gauge".

kcal is kilocalorie.

Metric count (Nm) is the number of kilometres of yarn per kilogram.

A nanometer (nm) is 10^{-6} mm.

rev/min is revolutions per minute.

Tex is the weight in grams of 1,000 metres of yarn; millitex (mtex) is 0.001 tex.

wpi is "wales per inch".

Worsted count is the number of 560-yard lengths per pound of yarn.

AIR CONDITIONING

by

A. [illegible]

Air installations play a very important role in textile plants and constitute an important part of their general administration. The movement of air is used in the textile industry for the transport of fibres, cleaning, yarn texturing, the drying of materials, the cleaning of machinery, dust removal, mist dispersal and the air conditioning of production departments. Because of their importance, most attention is given here to the problems of air conditioning, dust removal and the clearing of misty air.

The technical procedures in the processing of fibres very often require the maintenance of certain constant values of the air in production departments of the plant building. On the other hand, the process of the fibre treatment is, in itself, a source of air pollution, which adversely affects sanitary and hygienic conditions, the quality of the production, the condition of the machine rooms and the building structure.

The properties of the air inside textile factories differ greatly from those of the natural outdoor air. High dust concentrations and temperatures resulting from the action of the machinery prevail in almost all production departments. It should be stressed that the heat-load intensity in modern spinning mills at this time exceeds 300 kcal/m^3 and in the weaving mills, 100 kcal/m^3. Moreover, in the dyeing and finishing departments, there is, if not a high level of humidity, then a considerably elevated one as compared with the outdoor humidity, as well as concentrations of noxious gases.

Air conditioning of production departments

Air-conditioning installations are used in production departments in which the technical process requires the maintenance, throughout the year, of constant and exactly defined air parameters. These installations make the condition of the air in the rooms completely independent of the outdoor conditions, thus permitting the establishment and maintenance of desired conditions indoors.

Air-conditioning equipment should control the four following air parameters: temperature, humidity, cleanliness and air movement.

Within individual production departments, the following requirements should also be taken into consideration: *(a)* production and technological, *(b)* hygienic, and *(c)* technical and building construction.

TABLE 1. EXTRACTS FROM STANDARDS OF AIR PARAMETERS RECOMMENDED FOR PRODUCTION COMPARTMENTS OF THE TEXTILE INDUSTRY[a]

	French standards[b]	*Polish standards*[c]		*Soviet standards*				*American standards*	
				Temperature (°C)		*Relative humidity (per cent)*			
	Relative humidity (per cent)	*Temperature (°C)*	*Relative humidity (per cent)*	*Summer*	*Winter*	*Summer*	*Winter*	*Temperature (°C)*	*Relative humidity (per cent)*
Cotton mill									
Card room									
winter	45—55	24—27	50—75	22—24	23—26	60—65	60—65	24—27	55
summer								28—30	70—80
Preparatory department	50—60	24—27	55—65	22—25	25—28	50—55	50—55	27	60
Spinning room									
conventional spinning	50—65	24—27	55—65	24—27	27—30	50—60	45—55	27—30	70
fine spinning		24—27	45—55	24—27	27—30	50—55	45—55	27—30	50
Weaving shed	70—80	24—25	65—75	20—22	23—25	65—70	65—70	26—27	70—85

Woollen mill									
Preparatory department	70—80	24—27	65—75	20—23	26—29	50—60	50—60	27—30	65—70
Spinning room									
woollen spinning	65—75	25—28	55—75	22—25	26—28	55—60	55—60	27—30	50—60
worsted spinning	70—80	25—27	65—75	20—26	23—26	70—75	70—75	27—30	50—70
Weaving shed	60—65	22—25	60—65	20—23	24—26	65—70	65—70	24—27	65—70

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[a] All standards contain additional explanations showing deviations from the given values depending on the character of the fibres and their processing.

[b] In French standards, it is recommended that inside temperatures should not exceed 28°C in the summer and in winter should not be below 22°C.

[c] In Polish standards, a temperature of up to 29°C is permissible in production departments during summer heat. However, in auxiliary departments such as stores of rovings, yarns, warps, wefts, etc. it can be as high as 33°C.

Production and technological requirements

With unsuitable values of air parameters in production departments, production processes may undergo considerable disturbance. Many yarn faults, such as roughness and non-uniformity, fluctuations in the numeration and differences in yarn properties, are the result of unsuitable relative humidity levels and air temperatures in spinning mills.

The production process in weaving sheds has similar requirements as regards air parameters. Variable relative humidity of the air causes fluctuations in the stresses and extensions of the weft and warp, which in turn causes increased breakage and fluctuations in the fabric width. Quality consequently deteriorates, productivity falls and the proportion of waste rises.

The choice of optimal physical air parameters is sometimes difficult because of the complex nature of fibre processing. Thus far, there is no rule which allows them to be established univocally. Many years of experience have shown that the required temperature and relative humidity of the air depend not only on the qualities of the kind of fibres being processed (for example, their hygroscopicity) but also on the way in which the production process is conducted, such as the degree of fibre opening, the yarn number, the extent of stretching, the number of twists and the kind of weave. The material used to cover the guide rollers is also important. At one time, when calf hide was used, American cotton, for example, could be processed with a relative air humidity in the range of 60 to 70 per cent. At present, however, using synthetic fibre roller covers, American cotton is best processed with a relative air humidity in the range of 50 to 60 per cent.

The most reliable method for determining the optimal climatic conditions is observation of the process under various climatic conditions. However, this method takes much time, since a great number of experiments must be performed. Very unfortunately, it is not always possible to make use of experiments performed in other countries, because differences in fibre processing must often be taken into account. This can be seen in table 1, in which the air parameters recommended for textile mills in France, Poland, the Soviet Union and the United States are compared.

Hygienic requirements

In order to provide suitable working conditions for the operatives, ranges of temperatures, relative humidity and speeds of the air movement in which they can work most productively and feel comfortable must be maintained. When stressing the significance of climate for humans, the American scholar Ellsworth Huntington (1876–1947) showed, in his works concerning human geography, that one of the factors responsible for the rapid development of civilization in Europe is the temperate climate of that continent. Man acts and works best when he is neither too hot nor too cold. The adaptation of environmental conditions to the requirements of his organism increases his productivity and lowers absences attributable to illness (see figures 1 and 2). The measure of the cooling capability of the medium are effective temperatures (ET), which are a function of the temperature from a dry thermometer (t_d), relative humidity (φ) and the movement of the air (v). The effective temperature can be determined according to the following formula

$$ET = 100 \sqrt[4]{91.88 \quad \frac{\Delta K}{0.0885}} \quad 273$$

where ΔK $= K_g - K_{met}$

K_g = Kata value of a glass kata-thermometer

K_{met} = Kata value of a metal kata-thermometer.

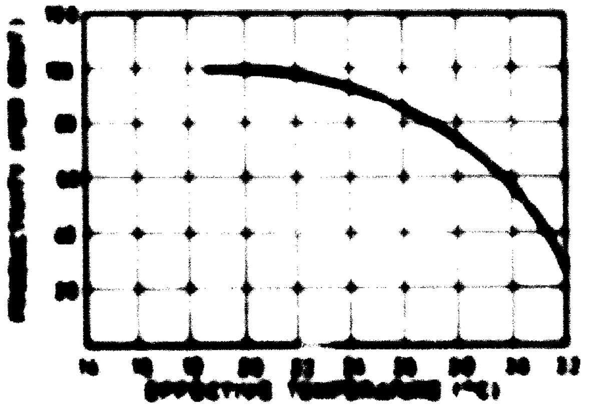

Figure 1. Worker productivity in relation to effective temperature

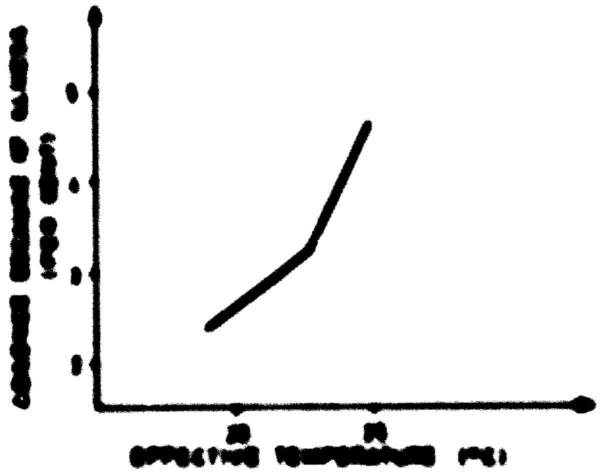

Figure 2. Worker absenteeism in relation to effective temperature

The values of the optimal effective temperatures are adjusted by suitable regulations that take into consideration the effects of acclimatization; for example, in both Poland and the United States, the recommended effective temperatures are in the ranges 17.1° to 21.6°C in winter and 18.9° and 23.9°C in summer.

Technical and building construction requirements

The correct size and operation of the air-conditioning installations are dependent, to a great extent, on the building structure itself. This mainly concerns the proper choice of materials for building construction, taking into consideration their thermal properties, so as to avoid undue losses or gains of heat and the condensation of steam on them, which directly affect the size of the air-conditioning installations and, at the same time, the consumption of electrical and heat energy.

It is recommended that the heat transfer factor (*k*) through the outside walls and especially through the ceiling, under the roof, at high relative humidities should exceed 0.5–0.7 kcal/m^2·hour·°C. This especially concerns climatic zones where there are great fluctuations of temperatures and also temperatures below the freezing point. To equalize heat balances and to eliminate the effects of outside conditions, new ways of constructing buildings and their internal walls are being sought. Special effort is being directed toward means of limiting the relative humidity within a room to 70 per cent. It has been found that too high a humidity can be avoided by carrying out production processes in a suitable manner. For example, if a starched cotton warp has only 12 per cent humidity, that of the air in the weaving mill need not exceed 70 per cent; indeed, a humidity as low as 65 per cent might suffice.

The principal parts of air-conditioning systems and their functions

Every air-conditioning system is made up of two basic groups of equipment: air-preparation devices and air-circulation devices.

The air-preparation equipment is comprised of the following elements: a mixing chamber, air filters, air heaters and a sprinkling chamber with full fittings.

The following are included in the air-circulation equipment: blowers, inlets, air-exhausts and ventilation ducts.

The basic air treatment takes place in the preparatory equipment where the air, depending on conditions both indoors and outdoors, is suitably mixed, humidified, heated or cooled.

Air-conditioning processes on the graph "*i–x*" of Mollier

The thermodynamic processes of the preparation of the air, illustrating typical air conditioning in the textile industry, is shown in graph *i–x* in figure 3, which illustrates a typical process of air conditioning by drying. This function consists of a mixing process (line *AB*), drying-cooling process (line *MO*) and the heat assimilation process in the room (line *OB*).

Figure 4 illustrates a typical air-conditioning process with humidification of the air when outdoor temperatures are higher than the indoor temperature. Figure 5 shows the air-conditioning process with humidification of the air when indoor temperature is higher than the outdoor temperatures. The characteristic feature of the air-conditioning process shown in figure 5 is the additional heating of the air before humidification (line *MK*).

The basic type of air-conditioning equipment that has been adopted in the textile industry has one circulation of air and a single-stage sprinkling chamber (figure 6a). Double air circulation (figure 6b) is applied only with variable and negative heat balances in order to protect the heating element from wear.

When water from mountain streams or from deep wells is available, air-conditioning equipment with two sprinkling chambers should be used (figure 7), since they make possible a decreased demand for water. Usually, with single-stage

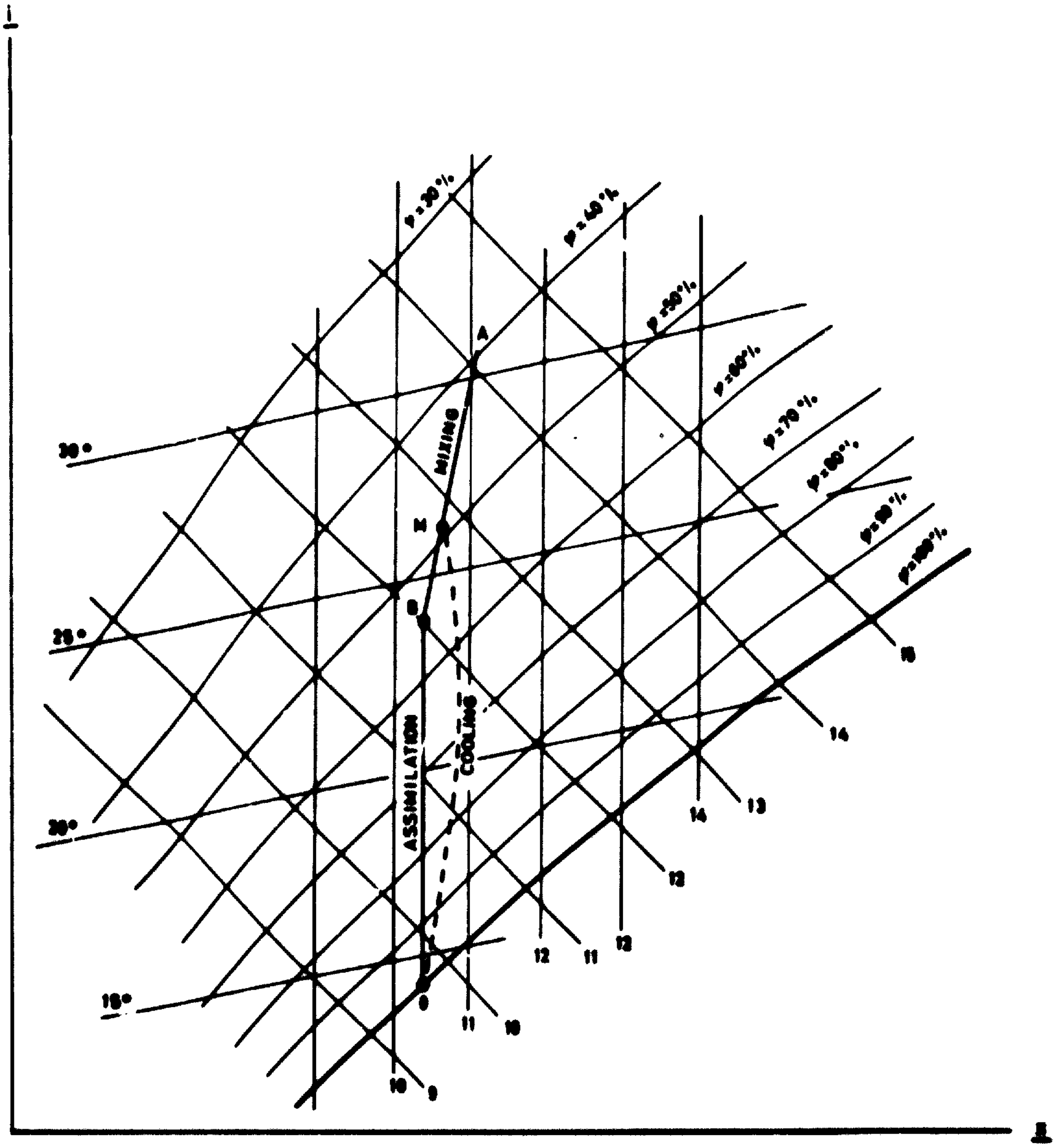

Figure 3. Typical run of air-conditioning process with drying (cooling) of air

sprinkling chambers, the rise in temperature of the water that receives the heat from the air is not more than 4.5° to 4.8°C, but with two-stage sprinkling chambers the rise can be increased by as much as 80 per cent.

The operating principle of a two-stage sprinkling chamber diagrammed in figure 7 is as follows:

Pump (*A*) sucks (*W*) cubic meters of water from the second-stage chamber and forces it through nozzles into the chamber of the first stage. Part of this water (W_1) flows out of the equipment through the overflow, the rest (W_2) after mixing with cold water coming from the outside source, is drawn up by pump (*B*) and forced through the nozzles of the second-stage chamber. The air in the chamber of the first stage is first cooled by contact with water that has been partly heated in the second-stage chamber and next passes through the inter-stage water-drop remover and reaches the second stage, where it reaches the required parameters.

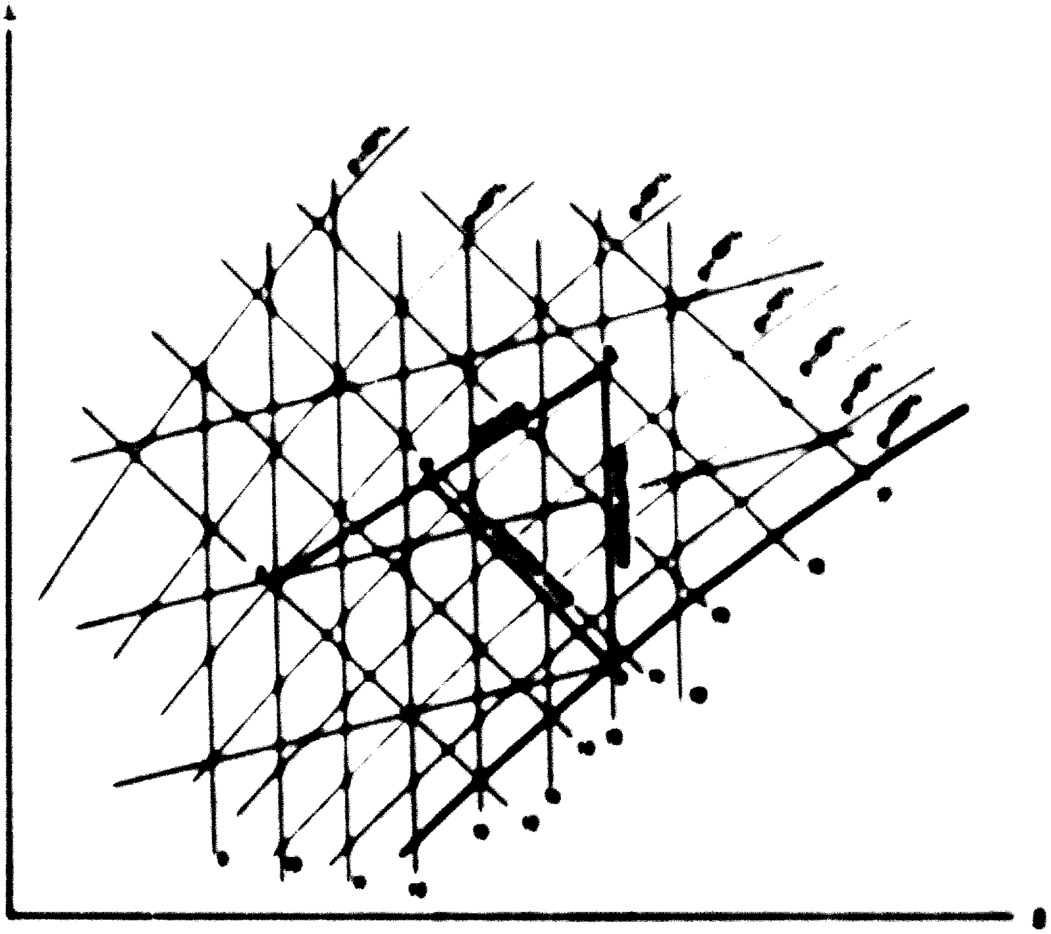

Figure 4. Typical run of air-conditioning process with humidification, when the outdoor temperature is higher than the indoor temperature

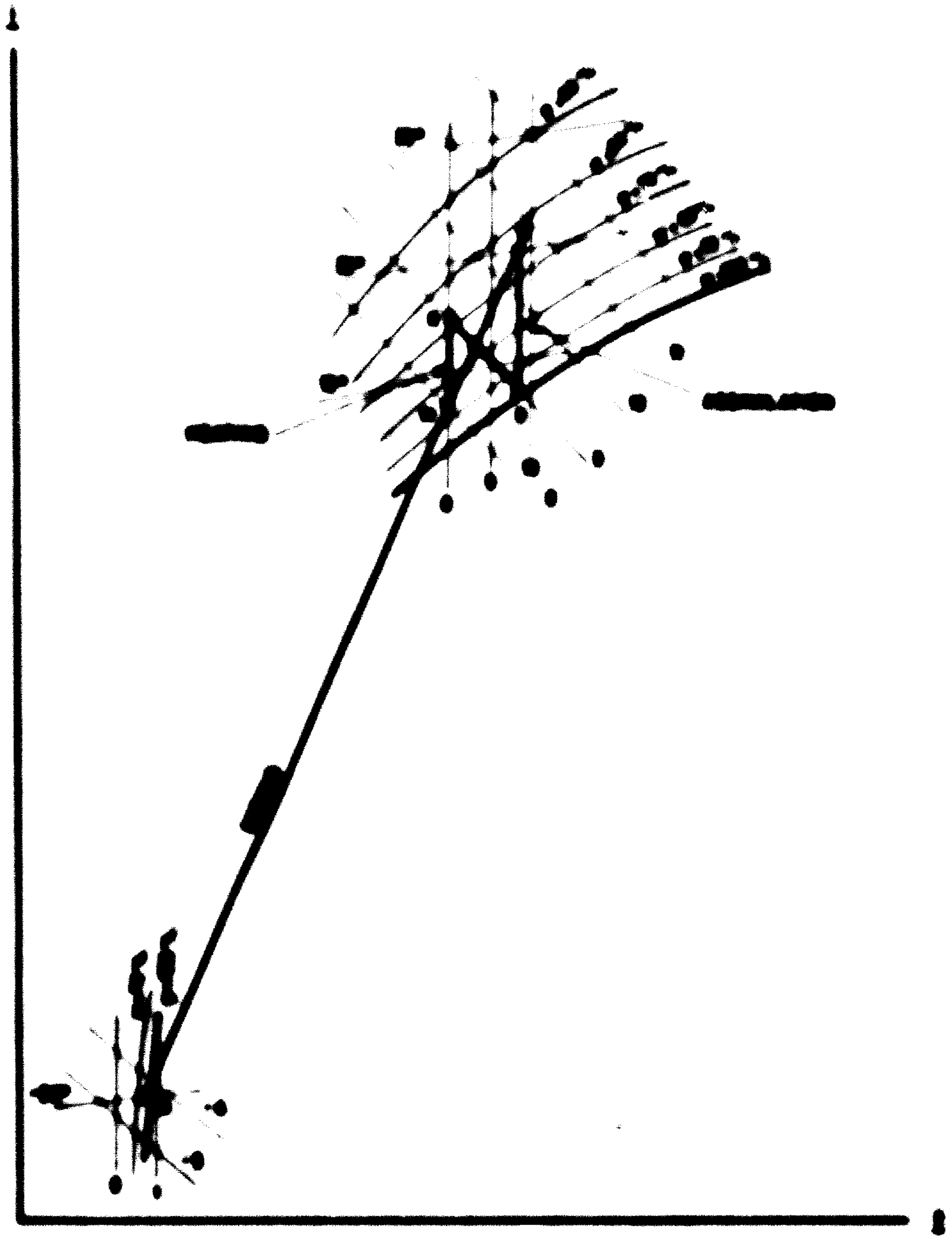

Figure [illegible]. Typical run of air-conditioning process with humidification, when the indoor temperature is higher than the outdoor temperature

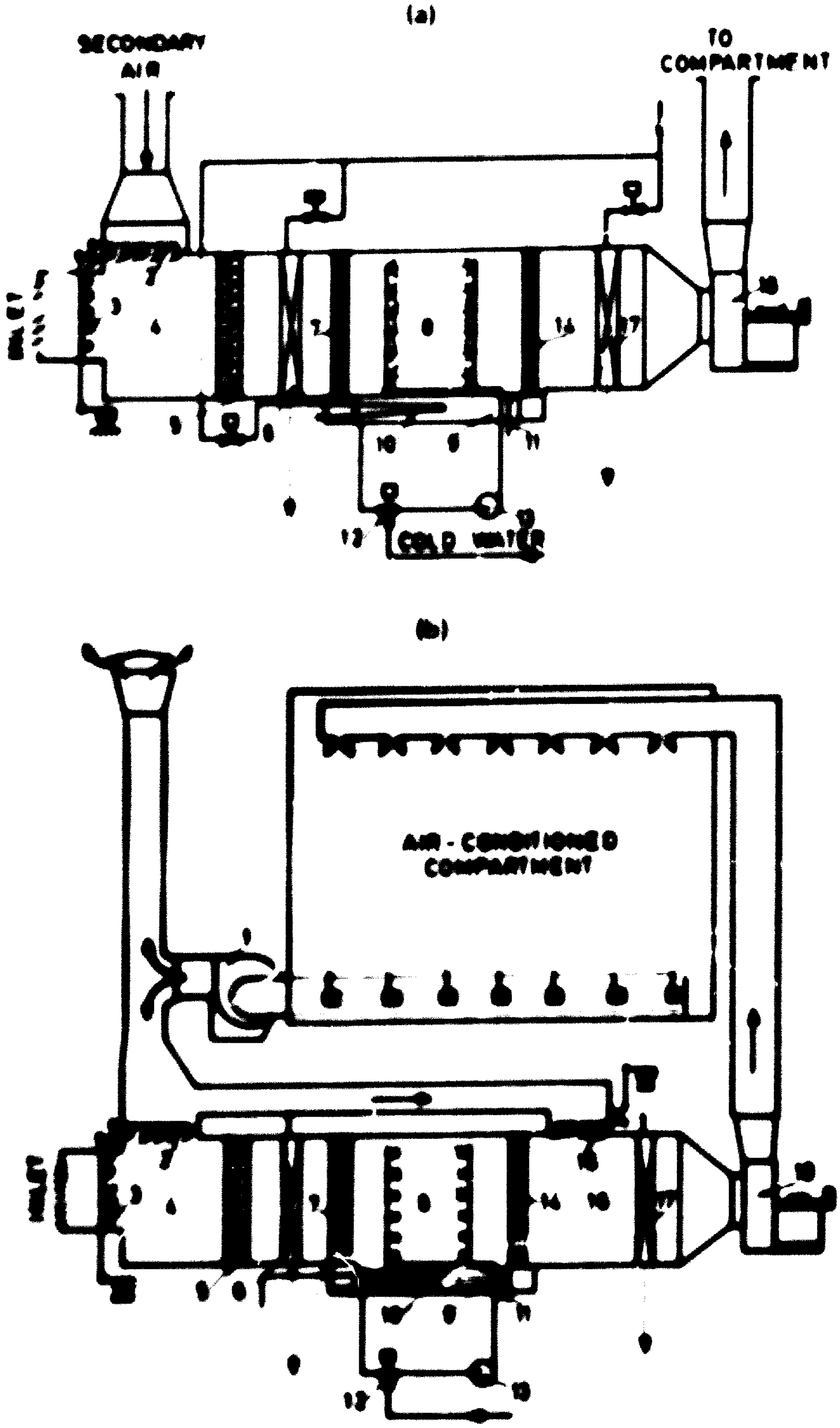

Figure 6. Air-conditioning equipment with one circulation of air and a single-stage sprinkling chamber (a) and with double circulation of air (b): (1) fan, (2) valve for circulating air, (3) valve for outside air, (4) first mixing chamber, (5) dust filter, (6) primary heater, (7) guide apparatus, (8) sprinkling chamber, (9) tank, (10) heater, (11) overflow, (12) three-way valve, (13) pump, (14) drop remover, (15) valve for second cycle, (16) second mixing chamber, (17) secondary heater, (18) supply blower

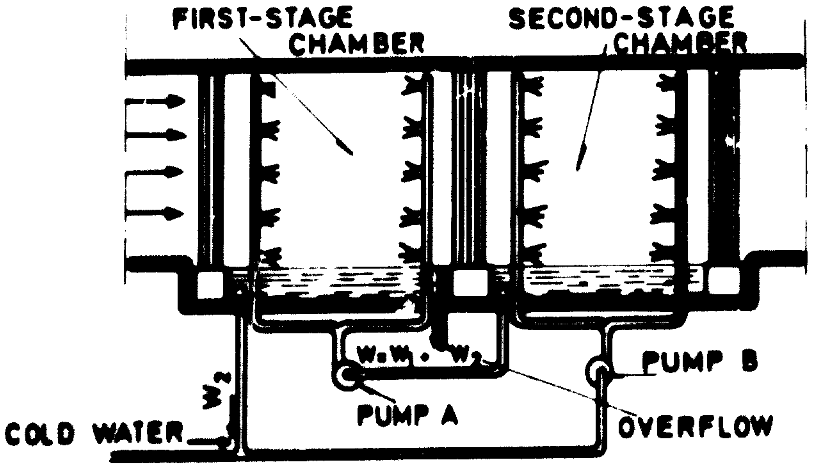

Figure 7. Air-conditioning equipment with two sprinkling chambers (see text)

Air conditioning with supersaturation of air

The air-conditioning equipment described thus far is often called "equipment with dry saturation" because, after humidification in the sprinkling chamber, the air passes through the water-drop remover, which eliminates drops of water that have not evaporated. Air-conditioning equipment with supersaturation of the air does not have a drop remover, and the air therefore carries water droplets into the rooms. The ability of the air to assimilate heat is thereby increased, because the air assimilates not only active heat but also the steam given off by the water droplets in the compartment as they evaporate, radiating heat into the room. The air-conditioning process with supersaturation of the air is illustrated on the graph *i* – *x* of figure 8.

In this process, the characteristic broken line *OB* symbolizes the process of assimilation of heat and steam within a room. Increasing the ability of the air to assimilate heat makes possible the air conditioning of rooms with fewer air exchanges; for example, for a required level of relative humidity of 65 per cent, applying a supersaturation of 2 g of water to 1 kg of air, the number of exchanges decreases by about one half.

Air-conditioning equipment with the supersaturation of air is constructed quite differently from equipment with dry saturation. Equipment of the first type (figure 9) does not have spraying chambers, but all the other elements, such as the drop remover (1), heater (2), valves (3), appliances for sprinkling the water (4) and a blower (5) are in one ventilation duct. Because of the drops of water carried into the room, they must be sprayed sufficiently high that they do not fall on the machinery and floor. For this purpose, special fog generators or an axial-flow fan working with a spraying disk are used.

Increasing the ability of the air to assimilate heat permits a decrease in the period during which the air-conditioning equipment must operate. Comparing the different air-conditioning systems that have been described, it can be seen that, with supersaturation, the ambient temperature in the room will be 1° or 2°C higher than without it. The temperature rise depends on the degree of supersaturation and on the level of the required relative humidity in the room. For this reason, the maximum supersaturation (2g/kg) is used with supersaturation equipment and, apart from this,

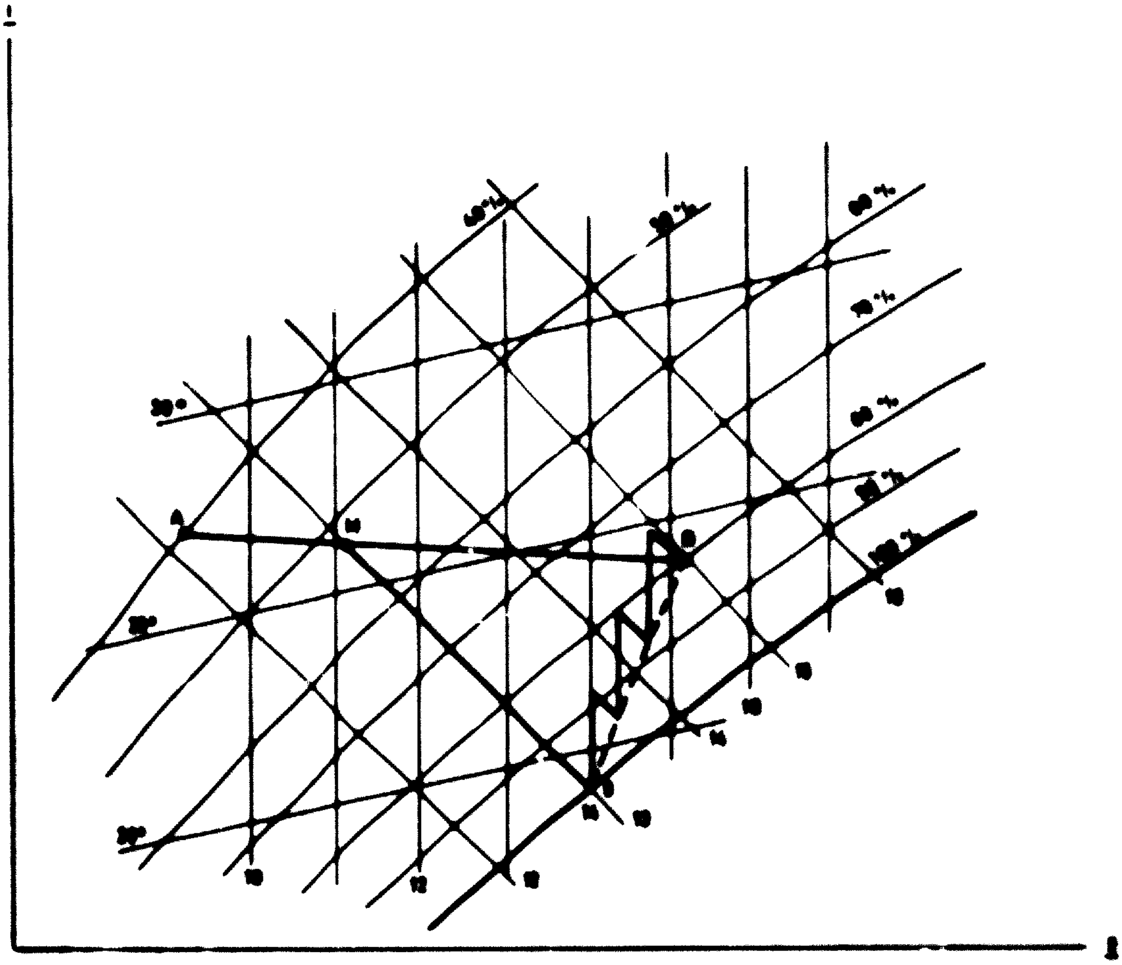

Figure 8. Curve demonstrating air conditioning with supersaturation of the air

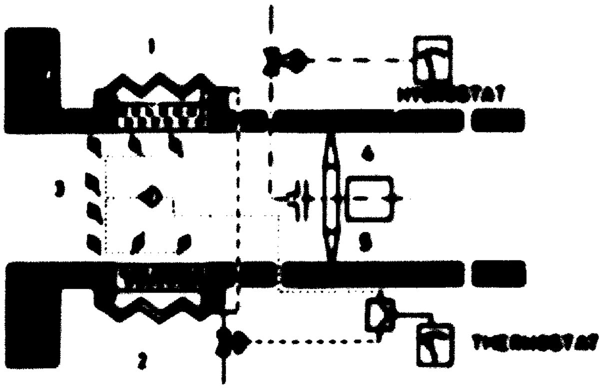

Figure 9. Diagram of air-conditioning equipment with supersaturation of the air (see text)

its application is limited to levels of humidity not less than 65 per cent. This limitation does not exist with air treatment with cold water. For this reason, air-conditioning equipment, shown in figure 10, was built for the first time in the Textile Research Institute. This is a vertical air-conditioning chamber with a normal sprinkling chamber and equipment for supersaturating the air, suspended on the ventilator axis. The air in this equipment can be humidified and cooled with circulating water from a tank or with cold water taken from mountain streams or from deep wells.

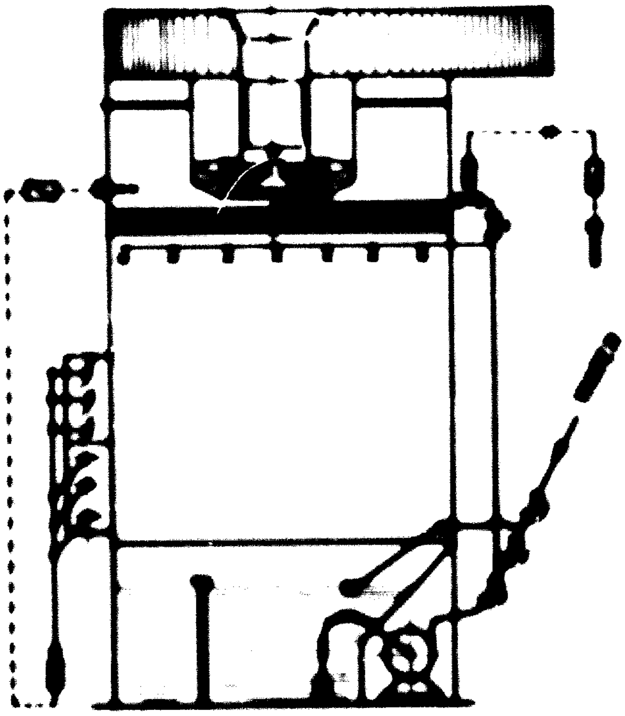

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Figure 14. Vertical air-conditioning chamber with equipment for supersaturating the air

Maintenance of air-conditioning systems

Because of the complexity of air treatment and the constant fluctuations of the outdoor conditions, the operation of air-conditioning systems is completely automatic. The controlling devices, which depend on the changes in the outside conditions, automatically control the mixture contents of both the outdoor air and the circulating indoor air, the amount of primary heating, the amount of secondary heating and the temperature of the water when drying the air. In the appliances for the supersaturation of the air, the degree of supersaturation is also controlled. The usual automatic control system is made up of two circuits:

(a) The circuit that controls the parameters of the air coming out of the sprinkling chamber;

(b) The circuit that controls the parameters of the air within the air-conditioned rooms in the building.

The first circuit consists of a thermostat that sends impulses through a differential relay to servomechanisms that operate gates in the air valves of the outdoor and circulating air and also the valve that closes the flow of steam to the primary air or water heater. When drying (cooling) the air the temperature control at the exit to the sprinkling chamber also sends impulses from a thermostat to the three-way valve that mixes the cold water with the circulating water in order to obtain the correct temperature.

The second control circuit consists of a hygrostat that sends impulses to the valve that closes the flow of steam to the secondary heater or to the servomechanism that operates the gates in the air valve at the entry to the secondary mixing chamber.

The use of only two circuits with two controls is possible because, in each circuit, the second air parameter is always constant. The air in the sprinkling chamber is of constant relative humidity (approximately 100 per cent), and the air in the room is at the appropriate absolute humidity. The most usual control system is pneumatic, although mixed electrical-pneumatic systems can be found.

In modern air-conditioning systems, the cleaning of the air and water filters is also automatic. The cleaning of the air filter (figure 11) is controlled by a pressure control that sends impulses to the appliance that operates the suction device that collects the dust from the filter. The suction device is put in operation by a fall in pressure in the ventilation duct caused by thick layers of dust on the filter. The water filter is rotary and runs continuously, and the dirt is washed from it by nozzles that spray it with water (figure 12).

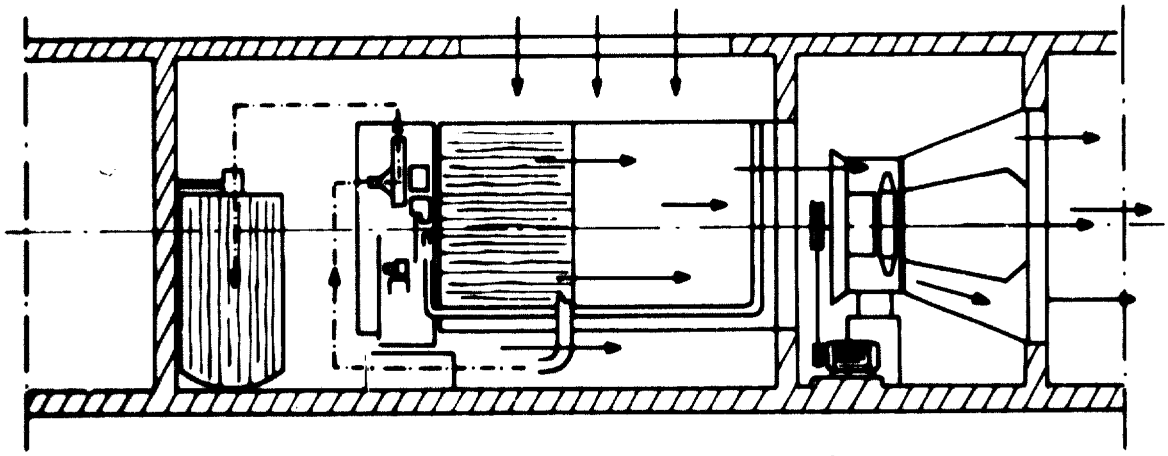

Figure 11. Operation of the air filter of an air conditioner

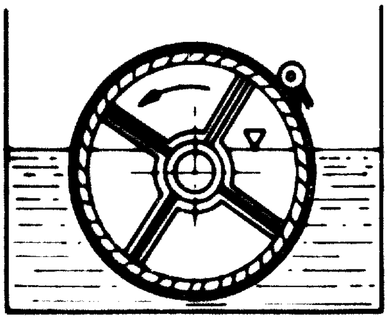

Figure 12. Operation of a rotary water filter for an air-conditioning system

The basic operations for the servicing of the air-conditioning system in a factory can be reduced to the maintenance of the individual elements of the system; that is:

(a) The cleaning and freshening (painting) of the ventilation ducts;

(b) The maintenance and replacement of damaged parts of the control fittings;

(c) The starting and maintenance of the electric motors and the pumps, blowers and compressors;

(d) The daily cleaning of permanent filters or periodic emptying of the dust containers of the mechanical filters;

(e) The periodic washing of the nozzles and removal of slime from the water tank.

Instructions for the performance of these tasks are issued by the makers of the equipment.

Adjustment of air-conditioning systems to the working conditions

A change in the kind of fibres or assortment of products being processed very often entails a change in the air parameters required for the rooms. In this case, the air-conditioning system must be adjusted to the new working conditions.

Because air-conditioning systems operate automatically, the problem is reduced to the appropriate adjustment of the temperature controls and the relative-humidity controls.

In the conventional double-circuit control system, the hygrostat, which is located in the air-conditioned room, is adjusted by a special hand-wheel for the level of relative humidity required by the changed processing conditions. The chief engineer should know what this value should be.

The temperature to which the thermometer (which is located at the exit for the air from the sprinkling chamber) should be adjusted, is determined from the curve i–x by plotting the direction of change of the air modification in the air-conditioned room. Since the direction of the transformation in spinning and weaving mills which are most often air conditioned is

$$\frac{\Delta i}{\Delta x} \rightarrow \infty$$

the point where the straight line x = constant cuts the saturation curve $\varphi = 100$ per cent gives the required temperature. In this case, the straight line x = constant must pass through the point, defining the new state of the air required in the air-conditioned room.

Clearing fogged air

The problem of de-misting is met with in finishing departments and dye-houses in which raw fabrics, loose fibres or yarn undergo bucking, bleaching, dyeing, washing, rinsing and other operations to give them their appropriate wearing properties. In most cases, these operations take place in baths, sometimes at high temperatures, often reaching 100°C. The high temperatures in the tanks cause the evolution of large amounts of steam which, in summer, form a "tropical" climate that is difficult to bear and, in winter, an unwanted steam-air mixture. The air in the finishing departments therefore must be dried and brought up to a state that will ensure good working conditions for the operatives and protect the buildings and machinery from rapid deterioration.

To clear the misty air, simple ventilation equipment is used, with heating of the air when outside temperatures are low. The mist-dispersal process is illustrated on the curve i–x (figures 13 and 14).

The exhaust for the used air is located at the highest point of the air-conditioned room, to which the highest concentration of steam, which is lighter than air, rises.

Where there is intense evaporation of water, the exhausts are located near the source, with the use of appropriate shields, eaves or edge suckers.

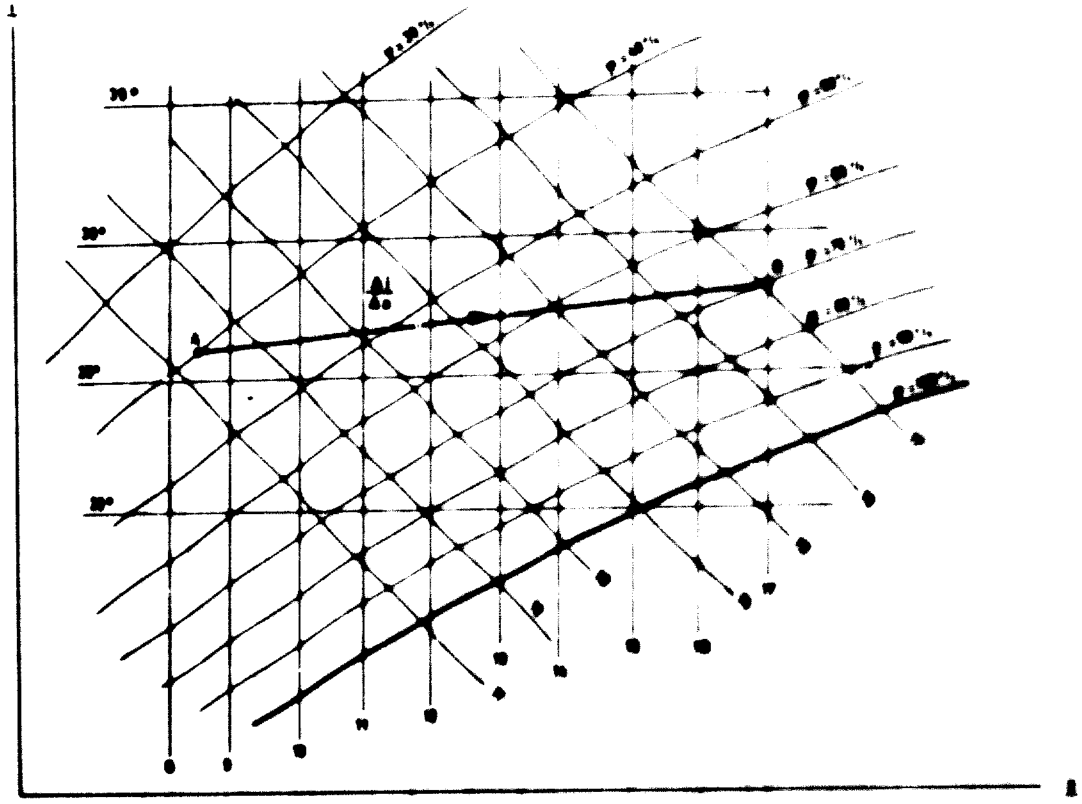

Figure 13. Curves for the clearing of misty air at positive outdoor temperatures

In modern machinery, the steaming surfaces are hermetically sealed in order to minimize steaming. In such cases, the use of local exhausts is unnecessary, since the problem of clearing misty air can be solved by simple general ventilation.

The hermetic sealing of the steaming surfaces not only limits steaming but also shortens the time required to heat the tanks and lessens the wear of the heating element. This can be demonstrated by the heating of tanks in a closed and an open washing vat, as shown in figure 15. The solution of this problem by sealing the steaming surfaces is very effective. Because of its simplicity, de-misting equipment requires no special discussion here.

Removal of dust from the air

Air-filtration equipment is an element of every air-treatment installation. However, in the textile industry, separate dust removal installations are used that are designed specifically for the removal of dust from the air and the machinery. This is essential, because some technological processes form so much dust that it is impossible to remove it without special equipment.

Very generally, the sequence of the dust removal installation consists in trapping the dust (suction devices), a pneumatic transporting system, a dust collector and equipment for removal of the air (such as an exhaust fan).

The primary problems in dust-removal installations include the size and shape of the suction devices, the speed of transport and the kind and size of the dust collectors. All of these elements must be designed with specific reference to the construction of the machinery, the kind of dust, the size of the particles, the dust

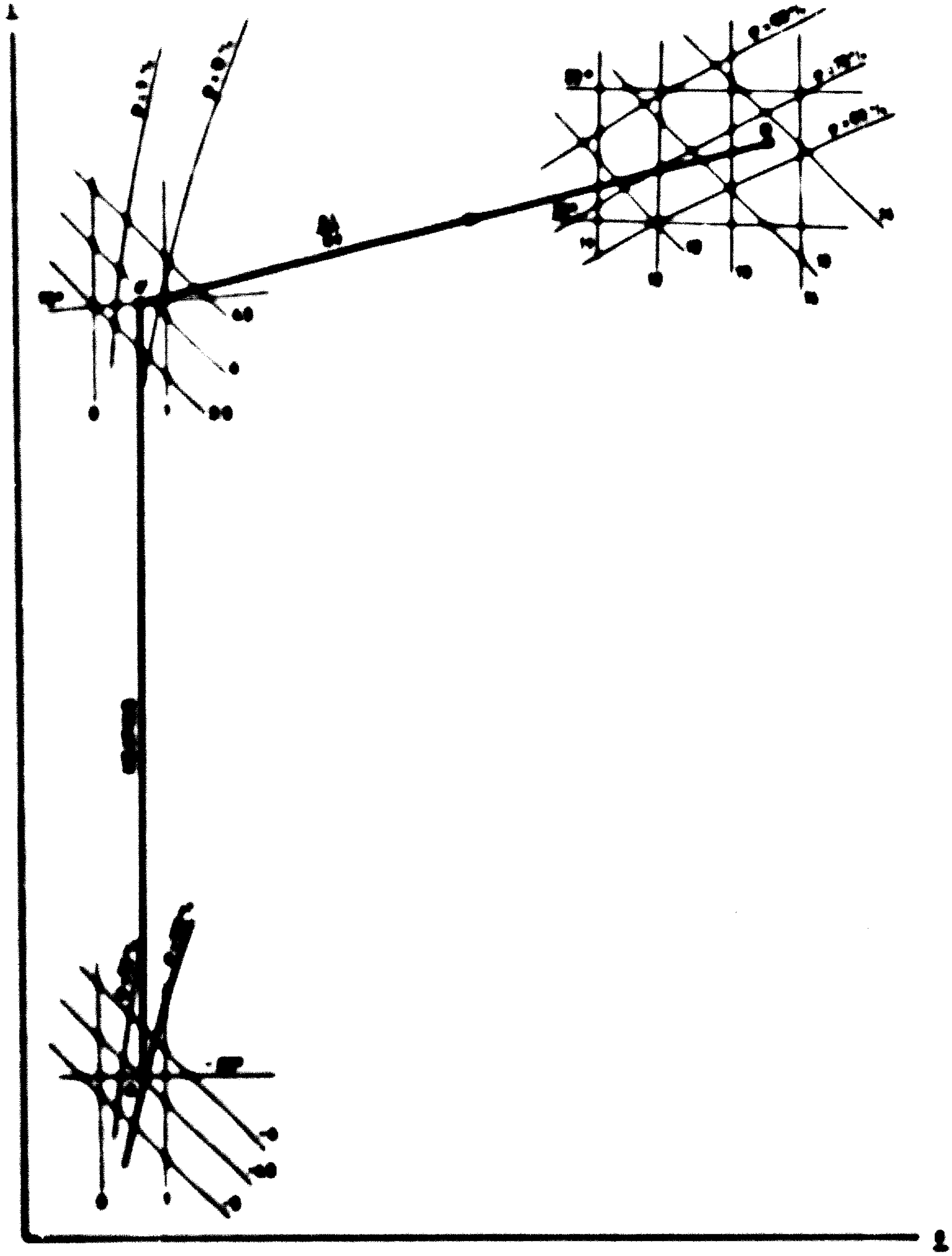

Figure 14. Curves for the clearing of misty air at negative outdoor temperatures

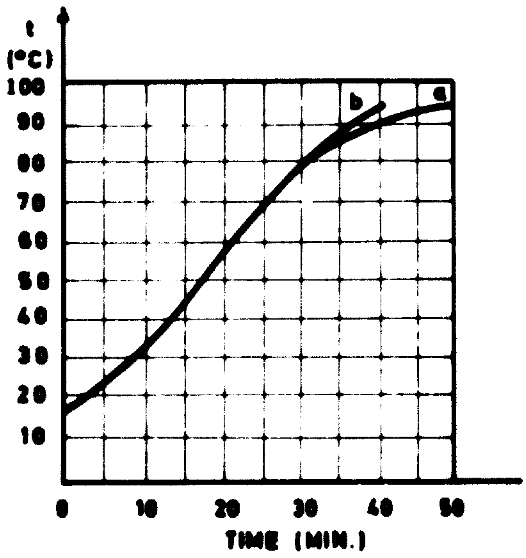

Figure 15. Course of heating of water in a washing vat: (a) with hood, (b) without hood

concentration, the required degree of the cleaning of the air etc. These problems are so complex that they cannot be discussed fully in the space available here.

In general, however, it should be said that problems of trapping the dust in modern textile plants are solved by the manufacturers of the machines. The correct location of the suction devices during the construction of the machine ensures the efficient removal of dust without causing interference with the production process. Since the rapidity of dust removal is connected with the speed of the transport and with the whole dust-removal system, modern textile plants have complete individual dust-removal installations in which a single dust collector serves several machines and even a whole department.

The most frequently used dust collectors are those of the sack fabric (sleeve) type, which consists of a series of long fabric sleeves through which the air flows, carrying the dust from the source. The dust-removal operation is completely mechanical, consisting in the stopping of the dust by the weft and warp threads as the air flows through the fabric.

In addition to sack dust collectors, cyclones, multicyclones, vertical filters, slide filters and the like are also used. The use of such devices is simple and requires no discussion here. All that is needed is compliance with the recommendations of their makers and good maintenance.

In conclusion, it should be stressed that, in the textile industry, air-treatment installations are the most important auxiliary production equipment. Indeed, it has been said, facetiously, that textile mills and fibre-processing plants are actually air-treatment factories. The importance of this equipment is evidenced by the fact that the amount of electrical power consumed by it may be roughly equal to half of that used in actual production.

STEAM AND POWER ENGINEERING

by

J. Wolański

Energy characteristics of textile plants

All technological processes in the textile industry are connected with the consumption of electrical and heat energy. The electrical energy is used to operate machinery, for lighting, sometimes for space heating and for technological purposes; the heat energy is used for heating and for technological purposes, because several processes require definite temperatures for correct operation or to obtain exact timing of operations. An analysis of the main production phases in the textile industry shows clearly that spinning mills, weaving sheds and finishing shops vary in their consumption of energy. Each stage of the production process has a slightly different energy characteristic.

Spinning mills

The spinning process, taken as a whole, is one with an exceptionally high concentration of mechanical work and that usually operates in normal thermal conditions, with the use of a great many machines, as in cotton and worsted spinning mills. There are certain divergences from this rule in woollen-spinning mills, which have some machines that consume heating steam. However, this group of machines is only a tiny part of the combing mill. This does not include the scouring of grease wool, which in some cases is part of woollen-spinning mill operations.

Spinning machines are driven by their own electric motors. In them, the electrical energy consumption per kilogram of yarn is always high, but this is especially true of ring spinning frames. Half of the electrical energy used by a cotton-spinning mill is used in these machines.

As examples, some typical figures can be given. To produce a single ton of 20 Nm yarn, 3,300 kWh must be used. With 33 Nm yarn, electrical energy consumption is much lower; that is, only about 2,000 kWh. Increasing the productivity of machines, especially by increasing their speed, implies the increase of electrical energy consumption per kilogram of yarn, because the consumption of energy rises more rapidly than the increase in speed. The heating of the production rooms in spinning mills is a complex problem because it is usually connected directly with air conditioning. Both heating and air conditioning are directly related to climatic zones, because the conditions that prevail in Poland and in Central and Northern Europe are quite different from those that prevail in the tropics, for example.

Another factor that increases electrical energy consumption is artificial lighting, especially the modern tendency to increase illumination. Furthermore, electrical energy is increasingly important in the mechanization and automation of transport. This brief survey shows that electrical energy is the most important form of energy used in spinning mills.

Weaving mills

From the point of view of their energy characteristics, weaving mills differ slightly from spinning mills in that they include a thermal process, namely, warp sizing. Apart from that, machine-operation, air-conditioning, heating, lighting and transport problems appear in weaving mills in much the same degree as in spinning mills, but with the added difference that in weaving mills higher relative air humidity and lighting intensity are required than in spinning mills. The fact that the electrical energy input into the air-conditioning appliances can be as much as 50 per cent as great as the power required for the production machinery shows that air conditioning has a great effect on the general electrical power requirements in spinning and weaving mills.

The interrelationship of the requirements for electrical energy and for heat energy in spinning and weaving mills can be shown by giving actual figures in reference to the accepted product unit (for example, per ton). These numbers fluctuate within quite a wide range; they can be, for example, 2,400 kWh/ton or approximately 5,000 kWh/ton, depending on the amount of weft per running centimetre, degree of air conditioning and the like. Steam consumption in weaving mills is not very great, being only about 6,000 kg/ton of warp. The total heat consumption in spinning and weaving mills per ton of raw fabric has been found, in several factories, to be 5×10^9 cal (for this, 10 tons of steam are required).

These figures show clearly that, above all in spinning and weaving mills, there are problems concerning the supply of electrical energy and that, on the other hand, the consumption of thermal energy is quite small, especially in countries with hot climates. The above-mentioned conditions affect, to a great degree, the general solution of problems of energy supply in plants that include only spinning and weaving mills.

Finishing departments

Significant problems of energy supply appear in factories with finishing departments. By such a department is understood one with a bleaching plant, a dye house, a print-works and a final finishing department. The finishing processes include many "wet" operations, among them drying, an additional special thermal processing and also a series of operations connected with the mechanical processing itself. These wet operations take place, partly at least, at elevated temperatures. However, they can run either continuously or intermittently, depending on the department. The baths can be heated to various temperatures, that is, below or above 100°C. However, the latter is done in closed pressure appliances (the method most often used today). Baths heated to temperatures not exceeding 100°C are situated mainly in pressureless appliances and machines, partly closed and partly open. This is the case especially when there is very high evaporation and misting of the air of the dye-house from open appliances and machines; this is one of the most serious problems in many dye-houses. While it is true that the introduction of a more or less hermetic construction gives very good results in coping with misty air, it does not solve this important problem completely. The thermal clearing of musty air by blowing air into the heated compartments also gives good results but is connected with an additional consumption of steam.

Drying is inseparably connected with wet operations. It is carried out in various kinds of driers, depending on the material to be dried and the requirements set by the drying process itself. Among the most often used convection driers are the stenter frame and the hot flue, short-loop and convection devices. In certain cases drum warping machines are used as contact driers. The temperature of the drying air is sometimes quite high (up to 150°C, and occasionally even higher).

The thermal stabilization process requires air or steam temperatures in the range of 220°C. The baking-curing process for fabrics padded with thermoreactive resins takes place in temperatures from 160° to 170°C.

Fabrics printed with vat dyes and some other must be steamed in an atmosphere of saturated steam (t = approximately 100°C) or heated to a certain degree (t = approximately 120°C). In order to achieve the required temperature of the baths and the air, it is essential to introduce heat. The most common vehicle for this heat is steam, usually saturated. This steam is used for direct heating by injecting it into the bath water and also for indirect heating by radiant or convection heaters or in heat exchangers. The second of these systems is used in driers, but the first is most often used for heating water-baths, although a tendency towards indirect heating can be seen.

Steam has several very significant advantages: it is practically neutral chemically, it condenses at constant temperatures, with the emission of much heat (latent heat), it is cheap and, for its production, only water which is available almost everywhere is necessary. However, in some places the water is not always usable (for example, in Lancashire), but boilers can be fed with water with a hardness of up to 12° on the German scale of water hardness.[1] However, steam has the important limitation that, because it condenses within the steam network, steam traps must be installed. These traps should allow only condensate to pass, but in practice, because of leaks, they let a certain amount of uncondensed steam through, thus causing large losses of heat and of money, since steam is fairly costly. Tests have been made in such conditions of the feasibility of replacing steam with another agent such as hot water at a correspondingly high pressure and in this way eliminating the heat losses caused by the defective operation of the steam traps. Such a change from steam to hot water may occur.

In general, steam at pressures from 3 to 6 atmospheres is used in finishing departments. However, the best conditions for the exchange of heat are provided by saturated steam. (If hot water is used, it must have the same pressure.) This saturated steam is at temperatures from 143° to 164°C.

In certain cases, as mentioned above, higher temperatures are required (up to 220°C). This takes place with thermal stabilization, and sometimes with curing apparatus. If steam with a suitably high pressure is available, it can be used to heat these machines. (To achieve an air temperature of 220°C, steam at pressures of 30 to 32 atmospheres is necessary.) In such cases additional electrical heating is used, although other solutions exist, such as heating with combustion gases or with hot oil. Space heating is of secondary importance in finishing departments.

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[1] In the German scale of water hardness, 1° represents 1 part of calcium oxide per 100,000 parts of water. 1° on this scale is thus equivalent to 17.8 parts of calcium carbonate per 1,000,000 parts of water.

In addition to heat problems, electrical problems appear in finishing departments connected with the machine drives, with lighting, with the clearing of misty air and with ventilation. Special attention should be paid to the machine drives, because not only the energy consumption itself is important, but also the arrangement of continuous production lines, that is, the role played by the choice of suitable types of electric motors.

The consumption of electrical energy per ton of fabric amounts to approximately 900 kWh, which is lower than in spinning and weaving mills. The heat consumption per ton of fabric amounts to about 15 to 10^6 kcal, for which approximately 30 tons of steam is necessary.

Because there is a large heat-energy consumption in finishing departments, usually carried by steam (in complete textile plants, finishing departments consume about 70 per cent of the total amount of heat produced), and quite a significant electrical energy consumption, and also because finishing departments are very often connected with spinning and weaving mills, where there is a significant electrical energy consumption, the manner of providing electrical and thermal energy is of very great importance. As a rule, large factories have their own power plants, which must provide all of the heating steam required. Electrical energy is most often absorbed from the factory's own power plant as well as from the power network. In certain cases, the factory power plant gives off excess electrical energy to the network. Co-operation of this kind with the power network is, however, not practical for the production factories.

The problem of producing electrical and thermal energy in factory power plants is discussed below.

Supplying textile mills with steam and electrical energy

The essential condition for the existence and operation of textile mills is an ensured supply of heat and electrical energy, the carrier of which is usually steam. As noted above, however, hot water is sometimes used. The size of this energy consumption and the inter-relationship between the consumption of electrical energy and that of heat energy (with the exception of heat energy obtained by changing electrical energy to heat energy) depend on the size of the factory and its production, as well as on whether the factory includes all departments or only some of them.

Textile mills usually have their own boiler houses to supply all of the steam or hot water required for space heating and for technical purposes. Thus, the condition most often set in the building of a boiler house is that it must supply all of the heat requirements of the factory. While the present development of power engineering in most countries permits the supplying of factories with electrical energy on quite convenient conditions, very many factories have power plants that supply their own requirements, partially or entirely. Whether or not a given factory will have its own power plant is decided by economic factors that can differ in each case. The specific operating conditions of individual factories determine whether a factory will have only a boiler house or also a power plant, and also the choice of the type of boilers, turbines, piston engines or other machinery that does not consume steam, such as internal combustion engines and water turbines.

If a factory has a boiler house that supplies steam only for technical purposes and for space heating (this situation is usually met with in smaller factories, as in the knitting and woollen industries), there is usually no necessity for boilers with steam pressures higher than 12 atmospheres. There will also be no need for such boilers to have steam superheaters, but it is advisable to have water economizers. Textile factories, especially those with finishing departments, are characterized by a very irregular steam consumption during a shift, mainly because many of the machines and dyeing apparatuses operate discontinuously; that is, cyclically. Such variation of steam consumption directly affects the operation of the boilers. If the steam requirements exceed the capacity of these boilers, then a fall in their pressure takes place, which in turn causes a fall in pressure in the pipelines that carry steam to the machines. Consequently, the boilers in boiler houses in textile factories should be capable of meeting the specific conditions of operation.

Lancashire boilers and the new packaged boilers (which are, in principle, Cornish fire-tube boilers) are adapted especially to this kind of non-uniform operation because they have a large water capacity and therefore a great steam-storage capability when pressure falls.

Flue-tube boilers are only slightly sensitive to the hardness of water; they can be fed with water of a hardness up to 12° on the German scale of water hardness. The principal limitation of flue-tube boilers is their low total output, which averages up to about 3 tons per hour. From this point of view, very much better results can be obtained with the above-mentioned packaged boilers, which can have very much higher outputs; for example, 10 tons per hour. Many factories have other types of boilers, such as those of the water-tube and radiant types. However, such boilers are sensitive to severe working conditions and require special preparation of the water. Even more complex conditions appear in factories that have their own electrical power plants.

Only rarely does a factory have a power plant that supplies electrical energy without also supplying steam for heating and technological purposes, because the power plants of textile factories normally supply both electrical energy and steam. This situation directly affects the choice of the steam turbines to drive the generators. If the power plants produce only electrical energy, the best selection would be a condensing turbine; however, when producing both electrical energy and heating steam, back-pressure condensing-extraction turbines or back-pressure extraction turbines must be considered. This kind of connexion is, of course, a classic example of the so-called coupled heat-power economy.

Condensing-extraction turbines of suitable size make it possible to supply the requirements of a factory for both electrical energy and industrial steam. This basic principle was generally followed before the Second World War, but in later years this situation has been completely changed. Also, actual conditions can deviate to a considerable degree from the neat theoretical assumption, especially when the steam requirement is large. In such cases, part of the steam by-passes the turbines, flows through a reducing valve and reaches the steam network. However, if a factory power plant is connected with the public power grid, and if the capacity of the plant's turbine (or turbines) is sufficiently great, the plant can discharge its excess electrical energy into the power grid.

In many cases, when it is possible to draw electrical energy from the public power grid, condensing-extraction turbines are not used and only back-pressure or extraction back-pressure turbines are installed. The reason for this solution is that, in the condensing part of the condensing-extraction turbines, large amounts of heat are lost, resulting in the production of electrical energy at a lower efficiency and at greater cost than in large power stations. With back-pressure turbines, steam is not lost in the condenser, and all of the steam, with a reduced heat content, is given off for technological and heating purposes. The heat cost per kilowatt hour of energy is in this case very low (e.g. 1,300 kcal). Apart from this, the entire installation of the back-pressure turbine is much simpler than for condensing-extraction turbines. Of course, pack-pressure turbines only partly cover the electrical energy requirements. Extraction steam or back-pressure steam usually has pressures in the range 3 to 5 atmospheres. If steam at higher pressure is required, an additional steam extraction is applied with a higher pressure. It is obvious that the choice of a given type of power plant depends on the conditions of a given factory and on economic considerations. In the power plants of textile factories, the choice of the type of steam boilers and their parameters, that is, the pressure and the superheating temperature, is important. Generally, over the last thirty years a tendency can be noticed to raise both of those parameters. As background, it can be stated that, before the Second World War, the steam pressure usually did not exceed 25 atmospheres, and the temperature of superheating was approximately 380°C.

Since that time, there has been a rapid rise in these parameters, as a result of which some textile factories have boilers with pressures of up to 90 atmospheres and temperatures up to 510°C. Superheating temperatures higher than 510°C require the use of very expensive austenitic steels.

With steam at such high temperature and pressure, the steam turbine is highly efficient. A large part of the heat content of the steam can be transferred into electrical energy and there is a resultant increase in the power supply from the factory power plant even with completely back-pressure turbines.

Steam turbines have, to a great extent, replaced the piston steam engines used previously. Piston steam engines are still being installed, but only sporadically, especially in small industrial plants. Modern piston steam engines belong, as a rule, to the group of standing, high-speed, back-pressured motors. The steam coming from these motors, at a pressure of several atmospheres, is utilized for technological and heating purposes. The possibility of contamination of the steam with oil raises certain objections that can be very important when the steam comes in direct contact with the water-baths. This can be avoided by fitting to the steam pipelines a de-oiling device, the efficiency of which depends on correct maintenance.

The boilers usually found in power plants of textile factories belong to the water-tube and radiant groups. Apart from their high output and high parameters, they are characterized by great elasticity; that is, they quickly adapt themselves to changes in load. Their outputs are sometimes as high as 50 tons per hour and even more. They are, as a rule, equipped with a water heater, superheaters for the steam and, sometimes, with air heaters. The boilers may be fired with oil or coal or sometimes even with gas. The choice of fuel used depends to a great degree on the fuel situation of a given country. For example, in Poland, only solid fuel (bituminous coal and lignite) is used for firing industrial boilers, but in France many boilers are fired with oil.

Liquid fuels are very much easier to use than solid fuels; they have higher net caloric value, they burn with a slight excess of air and produce very little ash. Boilers fired with them are easily regulated and adapted to various load conditions.

A very interesting development during the last ten to fifteen years has been the introduction of small steam generators of various constructions, outputs and sizes. The basic principle of their construction is that they have no drums or any similar elements of large water capacity; the water is pumped through pipes or coils. Generators of this type have a very low water capacity and consequently do not have the normal limits of conventional boilers. For this reason they cannot be set very close to the machines that they supply with steam. The generators may be started quickly and are used either to compensate for excessively high steam consumption or when certain machines, such as driers in the thermal-stabilization zone, require a supply of high-pressure steam.

In countries where there are cheap liquid fuels, it is advisable to install power plants equipped with large internal-combustion engines, such as diesel engines, to drive the generators. The advantage of this solution is the very highly efficient production of electrical energy; furthermore, the heated cooling-water (temperature of about 70° to 75°C) may be exploited directly for technological purposes.

At this point, mention should be made of the most recent tendencies in the development of power engineering administration in the textile industry, for example, in Poland. In centres that have high concentrations of industrial plants, the trend is to supply both electrical energy and steam from central thermo-electric power stations. In this way, such thermo-electric power stations are separate enterprises and no longer constitute parts of textile mills, which no longer need the boiler houses and power plant conventionally attached to them. Of course, the problems connected with the economical consumption of electrical energy and steam as carriers of heat do not disappear. In certain cases, it is possible to supply factories with hot water at a temperature of approximately 100°C instead of steam. This kind of heat supply requires adaptation of the whole network of the factory.

The design of industrial power plants requires a short discussion, and elaboration of the assumptions is very important. The basis of this elaboration is always the planned size of the factory from the point of view of its anticipated production capabilities and the kind of production planned. On the basis of these data, the required productive capability of the power plant and the output of the complex that produces the electrical energy can be determined, based on the indicators of energy and heat consumption per unit of production.

On the basis of the machinery that is to be used, the way in which it will be set up and the approximate estimation of its energy consumption, it is possible to determine the daily electrical and heat loads for both the summer and winter periods if, in the country in question, there are definite seasonal differences. Such graphic determinations constitute the basis for the choice of sizes of the boiler units and of the electrical current-forming complex.

In addition, a scale graph of the power engineering load, showing for how many hours in a year there is a given load, can be calculated. Such a graph provides additional information about the choice of boiler units and current-forming units and about the amount of reserve power required.

A further step is the choice of units and the elaboration of the basic power diagram of the factory. Once this has been done, design work on the project can be carried out.

Selected problems of power engineering administration

Recovery of waste heat

As already stated, the heat consumed during technical processes serves for heating all kinds of baths and air, and in some cases for the heating of surfaces. Apart from this, in the case of the drying of printed fabrics, the technological agent is steam, which is at the same time the carrier of heat. All of these agents are expelled after doing their work, periodically or continuously. However, their temperature is quite high: the temperature of baths poured into the sewerage system is sometimes about 100°C, the temperature of the air leaving the driers sometimes reaches 130° to 140°C and the temperature of steam leaving the agers is usually about 100°C. It should not be forgotten that heating steam fed into all kinds of heaters or driers, central heating installations and so on condenses in them at a temperature corresponding to the pressure of the steam, that is, for example, 140° to 150°C. After passing through the steam traps to the space where the pressure is nearly atmospheric, the condensate expands and as a result, part of it re-evaporates. Nevertheless, the steam traps permit some condensed steam to pass through them. As a result of these phenomena, a large amount of steam evaporates from the condensate containers.

Large amounts of heat escape into the atmosphere with the flue gases of the steam boilers, especially when these boilers do not have economizers and the flue-gas temperature is higher than 300°C. It may be said that an amount of heat equal to the whole amount of heat supplied for technological and heating purposes is lost in this way.

The removal of heat, sometimes at a high temperature, has drawn the attention of industrial power engineers to the possibility of recovering at least part of it so as to reduce expenditure of fuel and to rationalize technological processes.

Lost heat should be absorbed by an agent, such as water or air, that is easy to use. Hot water can be used directly for technological purposes if its temperature is sufficiently high for the given process; if not, it can be heated additionally. Hot air can be used for heating and de-misting building compartments, or it can be fed into steam boilers, thereby improving their heat balance. Generally, hot water is very much more useful than hot air, since water is easier to collect, heat and distribute.

The recovery of waste heat is always connected with the installation of suitable heat exchangers, pumps, hot-water containers and a complete network of pipelines for the distribution of warm water all over the factory. However, the pipeline network for the warm water must be independent of the cold-water network. Warm-water pipelines require adequate heat insulation, in the same way as steam pipelines. Of the above-mentioned heat losses, it is easiest to recover the heat from steam that leaves the condensate containers. An example of the amount of heat that can be recovered is given below.

If the heating steam is at a pressure of $p = 4$ atmospheres, the enthalpy of the condensate $i'_1 = 152.1$ kcal/kg. After expansion to normal atmospheric pressure, which roughly prevails in the condensate containers, the condensate has an enthalpy of only $i'_2 = 99.1$ kcal/kg. The difference between these enthalpies is

$$\Delta i = i'_1 - i'_2 = 152.1 - 99.1 \text{ kcal/kg} = 53 \text{ kcal/kg}.$$

This amount of heat (53 kcal/kg of condensate) can theoretically be recovered with a heat exchanger. However, in practice, slightly less is recovered (at least 80 per cent), that is, 53 × 0.8 = 42 kcal/kg.

If, for example, a factory consumes 50 tons of steam per hour, and if the return of the condensate amounts to 50 per cent, then the amount of recoverable heat (with correctly acting steam traps) amounts to

$$50{,}000 \times 0.50 \times 42 = 1{,}050{,}000 \text{ kcal/hour.}$$

Since, in actuality, steam traps permit uncondensed steam equivalent to about 10 per cent of the condensate to pass, the amount of heat in this leakage steam must be added to the heat calculated above. It must be taken into account that this steam expands to a pressure of 1 atmosphere. In this case, the amount of heat will amount to

$$50{,}000 \times 0.5 \times 0.1 \times 539.4 \times 0.8 = 1{,}080{,}000 \text{ kcal/hour}$$

The total quantity of heat that can be recovered (Q) here amounts to

$$Q = 1{,}050{,}000 + 1{,}080{,}000 = 2{,}130{,}000 \text{ kcal/hour.}$$

The amount of water that can be heated (W) can be calculated, taking, for example, the cold water temperature as $t_1 = 15°C$, and the hot water temperature as $t_2 = 65°C$. For the example above, it will be

$$W = \frac{Q}{t_2 - t_1} = \frac{2{,}130{,}000}{50} = 42{,}500 \text{ kg of water;}$$

that is, 42.5 m^3.

This is a large amount of water, and it could, to a great extent, cover the hot-water requirements of a cotton mill. It should be stressed here that installations for waste heat recovery from hot baths, hot air and the like already exist.

A more precise calculation of the waste heat shows that there is so much of it that it is impossible to re-use it completely with the help of hot water, because each factory (or more precisely, each finishing department) requires only a limited amount of hot water.

Considering the processes used in the finishing departments of various kinds of textile plants (cotton, woollen, linen etc.), it can be said that the greatest use of hot water can be made in the finishing departments of the cotton industry because of its many wet processes (bleaching, dyeing, washing). Very much less is used by finishing departments of the woollen industry, which affects the course of the technical processes and their requirements.

On the basis of tests carried out by the Textile Research Institute, it was calculated, for example, that in the finishing departments of cotton mills, the hot water consumption can reach approximately 10 litres/running metre. Taking into account the great production volume of cotton mills, it can be stated that warm-water consumption amounts sometimes to 100 m^3/hour.

From all of the foregoing, it can be concluded that, in any situation, that system should be used which recovers the waste heat most easily and gives the best results.

Since water that must be heated to a temperature of, for example, 95°C, requires very much less heat (and because of this, less steam) if it is already hot than does cold water, its use therefore positively affects the work of the boiler houses, because they lower the peak loading of the boilers. The load compensation of the boiler houses can be improved still further by using the fresh steam that is available during periods of lower demand. This is also true of heating water, except that this water is sent on to the hot-water storage tanks. Such tanks must be sufficiently large that they can collect enough water to cover every requirement. Experience has shown that they should have a capacity of three to four times the average hourly requirement of hot water

In addition to the accumulation of hot water based on the recovery of waste heat, another way of accumulating heat is by the accumulation of steam, with the use of Ruths steam accumulators. This method is based on the phenomenon that, in a closed vessel about 90 per cent full of water, the space above the water will be filled with steam and the water will be at the boiling point at the given pressure. By lowering the pressure within the vessel, an amount of water within it that corresponds to the fall of the enthalpy of the boiling water with a fall in pressure immediately evaporates off. If, for example, a pressure of $p_1 = 8$ to 9 atmospheres prevails in the vessel, then the enthalpy of the water is $i'_1 = 176.4$ kcal. With a fall in pressure (for example, to $p_2 = 4$ to 5 atmospheres), the enthalpy of the water decreases to $i'_2 = 152.1$ kcal. The difference between these enthalpies

$$\Delta i = i'_1 - i'_2 = 176.4 - 152.1 = 24.3 \text{ kcal/kg}$$

is consumed to evaporate this amount of water. With a very slight error, it can be assumed that, if the evaporation takes place at a pressure of, for example, $p = 4$ atmospheres, and l is the latent heat, then from each kilogram of water contained within the steam accumulator, the amount of steam (S)

$$S = \frac{i}{l} = \frac{24.3}{503.7} = 0.048 \text{ kg}$$

will be obtained. If the water capacity of the steam accumulator is, for example, 80,000 kg, then, by the calculated decrease in pressure, the amount of steam will be

$$80{,}000 \times 0.048 = 3{,}840 \text{ kg}.$$

Since this amount of steam can be supplied almost immediately, even very large peak requirements for steam can be covered; that is, it is possible to obtain amounts of steam that normal boilers could not supply in any way. It is here that the great advantage of Ruths steam accumulators lies.

For practical calculation of the amounts of steam recovered within given limits of top and bottom pressure, the Backstrom graph is used. The accumulators are loaded with steam at a suitably high pressure (not higher than the permissible maximum) in the periods when the boilers are less loaded and the steam pressure in the accumulators is high, and they are unloaded when the pressure in the network of technical steam falls below a certain limit.

The steam accumulators were first constructed (from 1923) for low-pressure charging (below 10 atmospheres), and they consequently required large water capacity to be able to meet the requirements. Indeed, some of these accumulators have volumes as great as 300 m³.

Tendencies in the development of the construction of steam accumulators went in the direction of gradually raising the charging pressure and decreasing the volume. The accumulators constructed at present have volumes of about 100 m³ and a charging pressure of 25 atmospheres. With such a high charging pressure, a great amount of steam is obtained per kilogram of water. For example, it can be said that, with a the enclosing limits of 25 to 10 atmospheres, the amount of steam from 1 kg of water will be approximately

$$S = \frac{228.8 - 141.6}{509.8} = 0.171 \text{ kg.}$$

Steam accumulators are very useful auxiliary appliances in boiler houses. In spite of these advantages, however, they are installed only sporadically at present, which is certainly not attributable to any progress in the construction of steam boilers that can operate flexibly with large load variations. Steam accumulators are especially useful in textile plants in which there are very great, but short-term, fluctuations of consumption of steam from the boilers, which consequently causes an inevitable drop in pressure, not only in the boilers but also in the technical steam network. This happens usually where hot-water accumulators cannot be used, for example, in woollen mills, in the finishing departments of decorative fabrics and in the finishing departments of silk fabrics. In certain cases, steam accumulators are also used in the cotton industry, especially when only a few machines must be used (agers, dyeing machines) after the working week has ended. In this case, significant savings in fuel are achieved because, with small loads, large boilers cannot be operated economically.

Hot-water accumulators and steam accumulators help greatly in compensating the loads of the boilers and raise their general efficiency by 10 per cent. The hot-water accumulators make it possible to recover 18 per cent of waste heat, thus reducing total steam consumption.

LUBRICATION

by

J. Wolański

Textile machines, like other machines, are, to varying extent, made up of moving elements; that is, those with rotary or linear motion. Wherever there is friction between two surfaces, mechanical energy is changed into heat energy. The greater the friction, the greater are the resistance moment and the power necessary to drive the machine, which can be seen from the equations:

$$M = 716.2 \frac{N}{n} \qquad (1)$$

and

$$N = \frac{Mn}{716.2} M \qquad (2)$$

in which N is the power expressed in metric horsepower, M is the resistance moment in kilopond[1] metres, and n is the number of revolutions per minute.

Analysis of the work of most textile machinery reveals that about 85 to 90 per cent of the power of the driving motors is used to overcome friction resistances in the bearings and other rubbing surfaces; only a small fraction of the total power consumed is used to overcome friction resistances in the raw material that is being processed. The direct result of the friction of the moving machine elements is the release of heat, which amounts to 632 kcal per metric horsepower hour and to 860 kcal per kilowatt hour.

If friction resistances are decreased, the amount of power needed to drive the machines is decreased correspondingly. This is of particular interest because the present tendency is to raise productivity and thus to increase the speed of the machines, with a resulting need for increasing the driving power (see equation 2).

Friction resistances appear mainly in the bearings of various kinds of rotating rollers and spindles and on the surfaces of the teeth of the geared wheels that are present in larger or smaller numbers in every machine. Other elements, such as guides and cams, very often appear sporadically and do not play an important part in the general balance of resistances of a machine; only in exceptional cases (stenter driers, equalizers) does friction on the surfaces of guides play an important part. A quite

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[1] The kilopond is the force represented by 1 kg of mass. It is equal to about 9.8 newtons. A kilopond metre is thus the force of one kilopond acting over a distance of one metre.

exceptional place is taken by shuttle looms, in which a large amount of power is necessary to throw over the shuttles.

The lubrication of slowly moving elements

With a few exceptions, textile machines require rather small driving power. Even the fast modern ring spinning machines and frame driers are driven by motors with outputs smaller than 20 metric horsepower. From this, it can be seen that special lubrication problems such as circulation lubrication with cooling oil do not appear here, although there are several specific problems for the textile industry.

As noted above, there are very many different kinds of rotating rollers in textile machines, and these rollers have various diameters, rotate at different speeds and have appropriate bearings. In the older machines, very simple slide bearings were generally used, although a small number of more complicated devices, such as ring bearings, were also used. In modern constructions, slide bearings have been partly replaced by anti-friction bearings. This concerns, as a rule, the bearings of the main shafts and those of the high-speed shafts and average-speed shafts, although it should be stressed that most shafts in textile machines rotate at speeds not exceeding 500 rev/min. Slide bearings are usually lubricated with oil and this kind of lubrication must be carried out quite often; for example, once per shift or once daily, which requires much labour. Replacement of slide bearings with anti-friction bearings (ball-, roller-, and barrel-bearings and others) has simplified the lubrication problem to a great extent, because anti-friction bearings are lubricated with grease, which is changed very seldom or merely added to. Anti-friction bearings greatly reduce friction resistances, which in turn reduces the required driving power of the machines.

Despite the various changes in construction, a great many slide bearings remain. This is especially true in the driving heads of spinning machines such as drawing frames, slubbing frames, ring spinning machines and twisting machines. These bearings are very often hard to reach, and manual lubrication is sometimes very difficult. Needless to say, the manual lubrication of the bearings of such equipment as driving heads takes a very long time and, during such lubrication, much oil is lost by pouring it at the side of, rather than into, the hole through which it flows between the surface of the rotating shaft and the bearings. It is thus understandable that central lubrication of bearings has been introduced. The central lubrication system includes the oil tank, the oil pump that draws the oil from the tank and forces it to the bearings, and several pipes. The principle is that oil flows to each bearing through a separate pipe. So as not to complicate the system and in order to shorten the piping, the lubricating system has main pipes and distribution pipes, and several pipes lead off from each distributor. The pipes through which the oil must flow to the bearings must be very flexible. For this reason, they can be made of copper, brass or plastic.

The accepted principle of central lubrication is to supply oil in amounts adequate for lubricating every bearing. Because of this, each bearing has a small doser in its pipe that regulates the amount of oil flowing to it.

The main pump that forces the oil to the bearings can be started manually or mechanically. With manual starting by a lever, it is enough to move the lever once or twice, and the required amount of oil flows to the bearings. A comparison of the labour time necessary to start the pump with that necessary to lubricate each bearing individually will illustrate the advantages of central lubrication.

A further step toward the rationalization of the central lubrication system is the installation of an appliance that activates the oil pump at set intervals. Such an appliance can, for example, be a cam disk rotated by a suitable timing mechanism. However, equipping machines with such appliances in their central lubrication systems does not free those responsible for machine maintenance from the routine checking of the condition of these appliances, which may fail because of a blockage in the pipes, squeezing or disconnexion between the pipe and the bearing, and so on.

For the lubrication of the above-mentioned bearings, machine oil is used with a viscosity in the limits of 5° to 6° on the Engler scale at a temperature of 50°C. At the same time the oil also lubricates the surfaces of the rubbing wheels in the drawing head.

The lubrication of spindles

More complicated problems appear with lubricating spindles, that is, the high-speed elements, which operate at speeds that often exceed 10,000 rev/min. Spindles appear in these groups of machines, namely roving and slubbing frames, ring spinning frames and twisting frames.

The spindles of roving and slubbing frames rotate at speeds of about 1,000 rev/min. Very often there are many faults when lubricating is done with oil of too great viscosity, that causes difficulties in starting the machine.

The lubrication of spindles of ring spinning machines and twisting machines has always been of great interest to the builders of textile machinery as well as to the makers of lubricating oils. In older constructions, the bearing of a spindle was like a slide bearing but, because of the great rotational speed, conventional liquid lubricants were used to form a layer of oil between the surface of the spindle and its bearing, as a result of which the surface of the spindle did not touch the surface of the bearing at all. The power needed to drive the spindle depends mainly on the viscosity of the oil used for lubrication. The spindle lubricating oils used for lubricating these bearings has a very low viscosity, amounting from below 2° to 5° Engler at a temperature of 20°C. If oils with viscosities up to 5° Engler at a temperature 20°C can be used when the number of revolutions amounts to n = approximately 6,000 rev/min, then when n = 9,000 rev/min it is essential that very thin oils be used, that is, with viscosities of about 2° Engler at a temperature of 20°C or even lower.

In newer constructions, anti-friction bearings have been introduced for spindles of ring spinning machines and twisting machines. These bearings are also lubricated with spindle oils. This solution gives better conditions of operation for the spindles, especially when rotational speeds are high. The direct result of this is a smaller power consumption per spindle (1 or 2 watts), that is, up to about 10 per cent less.

Checking the operation of the bearings

When the machines are in operation, it is essential to control the condition and operation of the bearings. The direct indication that the bearing is not operating correctly is its temperature; a bearing that is operating improperly heats excessively.

and in an extreme case, this could result in the burning-out of the bearing. A practical way to control the operation of the bearing consists in checking its temperature manually. If the bearing is so hot that it is not possible to keep one's hand on it (temperature over 50°C), then it should be checked, otherwise the rubbing surfaces could be damaged.

Improvement in the operation of the bearing usually can be achieved by lubrication with oil that contains a certain amount of graphite, which settles on the surface and smoothes out any irregularities.

Special lubricating problems and special lubricating agents

Among all the special problems of lubrication, only the most significant ones can be discussed here. One of the most important problems in lubricating textile machinery is the application of the so-called washable oils. Oils of this kind are required especially where they may soil the fabric, and this can happen, for example, in weaving sheds, in knitting departments and in finishing departments. This problem also appears in lubricating the rings of spinning machines. It is true that technology has at its disposal oils that contain substances which facilitate the washing of oil stains, however, it should be stressed that the oils that cause staining contain very small pieces of metal worn away from the bearings. As a result, washing is not always completely successful, and slight soiling remains on the fabric.

Modern finishing techniques, and especially thermal stabilization carried out in stenter driers at temperatures reaching 220°C, make it necessary to use suitable agents for lubricating the chains, because various lubricants applied at lower temperatures, such as grease, are of no value in such high temperatures. In the last few years, [illegible] lubricants have become available that are resistant to temperatures even as high as 600°C. Lubricants of this kind can be selected on the basis of the catalogues of the firms that produce them. It should be added that such lubricants are very expensive, for example, $35.00 per kilogram.

In the last few years, lubricants containing molybdenum disulphide (MoS_2) have become available. This compound has certain properties similar to those of graphite, but is much superior to it. The properties of MoS_2 result from its physical structure (plates). With the use of oils containing MoS_2, low friction factors are achieved, and the period between individual lubrications is lengthened. It must be added that the oils containing this compound are more expensive than the normal oils.

This discussion shows only very generally the great number of problems connected with the lubrication of machines as a factor with a definite effect on the correct operation of machines and on production losses caused by stoppages. It also indicates that production managers and production engineers should give great attention to this problem.

DRYING

by

J. Wołoński

Characteristics and ranges of application of driers used in finishing departments

Drying is one of the principal technical operations in the finishing of all kinds of fabrics, including knitted ones. It is the logical consequence of wet operations and is repeated many times in many cases, especially with printed fabrics. Drying normally involves heat loss except that, before thermal drying in the finishing departments, various kinds of squeeze are used, the construction of which depends on the purpose for which they are intended, since drying can be connected with other operations.

Generally speaking, the six following groups of driers used in finishing departments can be distinguished: drum driers, lie-on-air (jet-type) driers, short-loop driers, hot-air (hot-flue) drying machines, perforated-drum driers, and stenter driers.

Drum driers are used mainly in finishing departments for cotton fabrics and are used for drying after bleaching and dyeing. Their prime advantages are their great evaporation and low steam consumption (about 1.3 to 1.4 kg of steam per kilogram of evaporated water), but they have certain significant drawbacks, such as the stretching of the fabrics, despite the application of breaking drives.

Lie-on-air (jet-type) driers are modern devices that direct an air jet onto the fabric. They are characterized by high evaporation and output, quite low specific steam consumption (1.6 to 2.5 kg per kilogram of water) and very little stretching of the fabric along the warp. These driers can replace drum driers.

Short-loop driers are characterized above all by the fact that they dry the fabric completely without tension, since the fabric lies loosely on the rollers of a moving conveyor. These driers can be used especially for drying fabrics that are very sensitive to stretching lengthwise, that is, fabrics made from regenerated cellulosic filament and staple fibres, and for drying knitted fabrics. With most fabrics, they are used for drying after bleaching and dyeing. Fabrics, including knitted ones, can be dried in one or two tracks or even more. Driers of this kind have superseded the so-called long-loop driers that were used formerly.

Hot-air (hot-flue) drying machines are also used for drying dyed fabrics. In driers of this kind, the fabric runs through a drying chamber, passing between two sets of rollers (upper and lower). Air is blown onto the fabric either directly or at a tangent, or by jets placed along the fabric on both of its sides either over its entire length or only over part of it, which is a feature of the latest versions. Driers of this kind are used either individually or in sets, which is the case in the aggregates for the Thermosol or pad-steam methods of dyeing. The driers are equipped with a drive that makes it possible for the fabric to pass with the lowest possible longitudinal stress. Another of their advantages is that, while their dimensions are comparatively small, their outputs are high.

Perforated-drum driers, which were used originally for drying loose fibres, are now being used also for drying fabrics, and especially knitted ones. They are characterized by high output and comparatively low specific steam consumption. Their primary drawback is the need for a rigid drive for each individual drum, another is that driers of this type do not have the ability to widen the fabric, which is stretched along the weft to a constant width.

Stenter driers are of four kinds: those that blow air along the surface of the fabric, driers that blow air across the fabric, driers with drums for pre-drying lateral ventilation, and jet driers. There are horizontal and multi-layer stenters into which the fabric is introduced by two chains, which serve to widen the fabric to a given width and to transport it in this stressed state through the drying chamber. However, the chains make it possible to obtain shrinking along the warp for which there is a suitable drive system that permits adjustment of speeds. Stenter driers are used to dry nearly all fabrics, including certain knitted ones. Final drying is usually carried out on these driers, but they are also very often used for drying between earlier finishing operations.

Stenter driers have undergone greater constructional changes over the years than those of any other type. These changes concern the action of the drier itself as well as its output. Modern stenter driers are, as a rule, constructed as nozzle driers, in which air is blown at great velocity directly onto the fabric through a great number of holes or gaps (so-called nozzles). Because of this, and also because of the adoption of the principle of the greatest possible difference of temperature between the dry- and wet-bulb thermometers, the amount of heat applied to the fabric by the air has been increased significantly. The evaporation of moisture from the fabric follows the two basic formulae that characterize the heat and mass transfer, in which Q is the quantity of heat (kcal/hour), F is the total area of both sides of the fabric, α is the heat-exchange coefficient, β is the mass-transfer coefficient, t_s is the dry-bulb temperature, t_m is the wet-bulb temperature, W is the amount of water evaporated (kg/hour), R_s is the gas constant of steam, T is the absolute temperature of steam, P_{ss} is the absolute pressure of steam on the surfaces, and P_{sa} is the absolute pressure of steam in the drying air:

$$Q = F\alpha(t_s - t_m) \tag{1}$$

and

$$W = F\frac{\beta}{R_sT}(P_{ss} - P_{sa}) \tag{2}$$

In modern jet driers, from 1 m^2 of the dried fabric, an evaporation of 30 to 35 or even 40 kg/hour is achieved, the high values at high heating steam values. Such evaporation intensities are higher than those attainable with perforated-drum driers, which are no longer used for slight pre-drying in modern stenter driers, although drums of this kind were essential elements of stenter driers built before 1945. Driers intended for use with fabrics of light or middle weight are constructed as single-passage machines. Depending on the requirements, they can have evaporation rates in the range of 1,300 to 1,400 kg/hour with fabrics 160 cm wide. The rapidity of the run of the fabric in such driers has been raised as high as 200 to 250 m/min. However, it should be stressed that thick fabrics, such as most woollens or some very thick cotton ones, should not be dried in driers with such high intensities of evaporation, because the fabrics dry mainly in their surface layers, while the inside of the fabric remains wet. For this reason, jet driers with an evaporation intensity not exceeding 10 kg/m^2/hour are used to dry woollen fabrics. To conserve space, such driers are built in layers (as many as six) and are known as multi-layer stenters.

Because of their great advantages, jet driers have superseded practically all of the older types of driers, such as those mentioned above that blow the air along or across the fabric. Driers of these older kinds are rarely built now although many of them are still in operation.

The automation of these driers and changes in their drive systems have also caused a great rise in their evaporation and output rates. The old driers had driving systems with very complex gears, but the present frame driers, which are coupled with padders, are equipped with double-motor driving systems. However, the electric motors can be regulated either steplessly, as regards speed, or they may be coupled with gears that permit stepless regulation of revolutions per minute within a wide range. Another constructional feature of the new driers is a drive system that makes possible the introduction of more fabric on the chains than their linear speed amounts to. This is the so-called "overfeeding" system, with which it is possible to achieve much more shrinkage of the fabric during the drying.

The stressing chains that widen the fabric can be made as pin chains, clip chains or combined pin-clip chains. In the older frame driers, the fabric was introduced on the chains manually, with the result that the position of the edge was not uniform but varied when the fabric narrowed suddenly. With manual pinning of the fabrics to the chains, the travelling speed of the fabric did not exceed 20 m/hour. However, by using the system that automatically controls the position of the chains in the pinning zone in relation to the edge of the fabric, the possibility of increasing the speed of the driers to 250 m/min has been achieved.

Between the drier and the padder there is a compensating roller, called the faller roller, which, depending on the tension of the fabric, raises or lowers and decreases or increases the speed of the padder, thus permitting good co-ordination of the two machines (the drier and the padder), with very low stress along the fabric.

The stenter driers, as well as driers of other types, are now equipped with instruments for measuring and recording the moisture of the fabric, because it has been noticed that the residual moisture of the dried fabric affects the drying process and the properties of the fabric. However, in industrial practice, a tendency to overdry the fabrics can be seen. Of all the different types of moisture controller, the most usual at present are appliances that measure the moisture of the fabric on the basis of its changes in electrical resistance.

In recent years, equipment has appeared for the automatic straightening of the weft in the fabric. This is important, since the operative has no means of controlling manually the elements that serve to straighten the weft.

Calculation of the output of frame driers

When buying a new fabric dryer of any type, it is important to calculate its production capacity. As a basis for such calculations, the tender evaporation (W_t) is assumed. Since the permitted tolerance is 10 per cent, this figure should be decreased in that proportion to find the real calculated evaporation (W'_c); that is, $W'_c = 0.9\ W'_t$.

Modern jet stenter driers with high rated outputs only achieve them when all of the requirements given in the tender are fulfilled. When other conditions are present, some quite serious errors may appear. If, for example, it is accepted that a drier will have a guaranteed output when drying a cotton fabric of a width equal to the maximum operating width of the drier (b_m) and with a mass (M) of 100 or 125 g/m^2 in an absolutely dry state, with a linen weave, not raised, not finished, drying normally, brought to the padder-drier aggregate in a dry state, padded in a padder with clean water, with a moisture (m) at entry into the drier m_1 = 100 per cent and moisture at its exit m_2 = 8 per cent, and the pressure of the steam (S) is equal to that specified in the tender (for example, p = 4 atmospheres), then the speed of the drier (V) will be

$$V = \frac{S_c \times 10{,}000{,}000}{b_m G_M (m_1 - m_2)} \ [\text{m/hour}] \tag{3}$$

where V is given in metres per hour, the heat of the steam in calories (S_c), M in grams, b_m in centimetres, and m_1 and m_2 in percentage. If actual conditions vary from those specified in the tender, a certain correction factor (K) should be introduced into the calculations. Formula (3) then takes the form

$$V = \frac{S_c \times 10{,}000{,}000}{b_m G (m_1 - m_2)} K \tag{4}$$

The factor K is the product of a series of component factors k_1, k_2, k_3 etc. which take into consideration the effect of each divergence on the conditions given in the tender, such as: the weight of the fabric, steam pressure, fabric weave, fabric raising, the bringing of the fabric to the aggregate padder-drier in a wet state, raw material, moisture of the wet fabric, moisture of the dry fabric, kind of finish with which the fabric was padded in the padder, the altitude of the location of the drier, the width of the fabric, the impurities on the filter of the circulating air and the conditions of the air that surrounds the drier.

$$\text{Therefore, } K = k_1 \times k_2 \times k_3 \times k_4 \ \ldots \times k_{13} \tag{5}$$

In practice, some of the factors can be omitted, if it is assumed that they equal 1.

In addition, when calculating the rate of production, stoppages for technical reasons must be taken into account. The real average speed (V_r) of the drier is then calculated according to the formula

$$V_r = V \frac{B}{B + \tau_p V} \ [\text{m/hour}] \tag{6}$$

B is the size of the batch (in running metres) in which there are stoppages caused, for example, by a change in finish;

τ_p is the down time (in hours) required to readjust the machine because of changes in the batch being processed; and

V is the speed of the drier as calculated according to formula (4).

Estimation of the power required to operate the drier

In the use of driers, the consumption of heat (usually supplied by steam) is important and may sometimes be very high. The simplest measure of heat consumption is the indicator determining the heat consumption per kilogram of evaporated water. If we assume that steam is the carrier of heat, then the indicator of heat consumption is the amount of steam (s) consumed for the evaporation of 1 kg of water; that is,

$$s = \frac{D}{W} \ [\mathrm{kg/kg}] \tag{7}$$

where

D is the total steam consumed by the drier (kilograms) and
W is the total evaporation of the drier (kilograms).

In very favourable conditions, the indicator s can be approximately 1.6 kg/kg, but it is usually higher. With incorrect operation, it can amount to 4 to 5 kg/kg and even more.

If the indicator s is too high, the reason for this must be sought. Generally, it will be found to lie in the faulty operation of the steam traps, which should always receive proper attention.

AUTOMATION

by

W. [illegible]

Automation is a field of science and technology, the purpose of which is to replace man, partially or completely, by automatic devices that perform the functions of operation, control and supervision of machines and also to control the products to the extent that the human hand does not touch them between the first and final phases of the production process.

In a greatly simplified form, human actions in industrial production may be characterized as follows:

(a) Physical activities in which human muscles are used, usually controlled by the nervous system;

(b) Measurement and comparison of the results of physical activities;

(c) Control (that is, conscious direction) of the activity, according to an established programme;

(d) Calculation of the physical and mental actions performed;

(e) Projection of a plan of action; that is, a programme based on the acquired knowledge accumulated in the memory, on experiments and on the results of the preceding action process. The programme is thus a product of the mental process.

The use of human muscular energy in industrial production has been largely eliminated by mechanization.

According to the definition of automation given above, the machine should assume functions that correspond to the higher levels of human activity; that is, functions of a mental nature, such as measurement, comparison and directional activities, according to the established programme.

The range of mental activities that includes logical functions such as the arrangement of plans of action (that is, programme planning), still remains beyond the capabilities of machines. In practice, automation means the introduction of automatic (that is, self-acting) controls in industrial processes.

The purposes of automation

Automatic control devices are employed industrially not only with regard to their technological and economic effects but also for humanitarian reasons.

The advantages of automatic control are many, such as greater productivity, higher quality of the products, greater uniformity of the products, more economical processing of the materials, more economical management of energy, and reduced human effort.

All of these factors generally lead to increased productivity. Also, the wide introduction of automatic controls into industry has necessitated the elevation of the levels of qualification and education for a considerable number of formerly semi-skilled workers who are needed for the operation and maintenance of control devices and equipment.

The basic concepts of automatic control

Automatic control can be defined as the maintenance of a desired value, quantity or state by means of measuring the real value, comparing this value with the desired one and obtaining their difference, so as to permit the initiation of activities that will lead to a reduction of any difference that has resulted from disturbance of the operation. An automatic control thus requires a closed-action circuit and a reaction produced without human participation.

The distinctive feature of a controlling activity is that it takes place within a closed system in the direction from the controlled variable to an error, then to a manipulated variable and again to the controlled variable (figure 1).

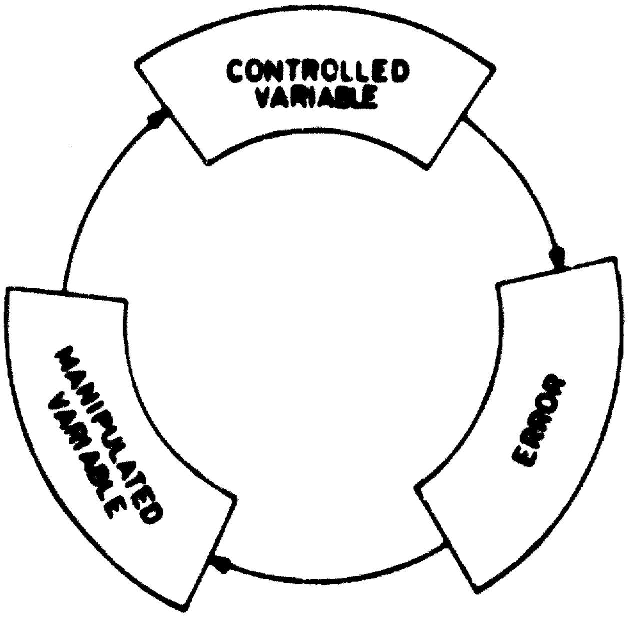

Figure 1. Control action in a closed circuit

The closed control circuit can be divided into two parts. The first part is a plant; that is, an aggregate of controlled devices in which great quantities of energy and material are used and processed. The second part of the circuit is a controller; that is, a device that incorporates many separate instruments, such as sensors, amplifiers and adjusting elements. It comprises those parts of the automatic control system that usually receive small quantities of energy.

A controller normally operates in either of two ways. If it measures the controlled variable, the deviation estimate and the manipulated variable without interruption, it is termed a "continuous controller". The other type is the "impulse controller", which performs its functions periodically (that is, with pauses). There is also a quasi-continuous type of control that results from the application of a non-continuous (impulse) controller that has supplementary mechanisms for objects of great inertia.

Continuous controllers may be divided into several groups according to the way in which they react to the error of the controlled variable, as follows:

(a) Proportional controllers (P);

(b) Integral controllers (I);

(c) Proportional-plus-integral controllers (PI);

(d) Proportional-plus-derivative controllers (PD);

(e) Proportional-plus-integral-plus-derivative controllers (PID).

Generally speaking, the controller estimates the value of the controlled variable, compares its actual value with the desired one, estimates the deviation and produces the counteraction required to obtain the smallest possible deviation value. To perform these activities, a controller incorporates a measuring unit, an input unit, a comparison element and a control-adjusting unit. Figure 2 is a schematic diagram of a closed automatic control circuit, showing its relation to the plant and its component units.

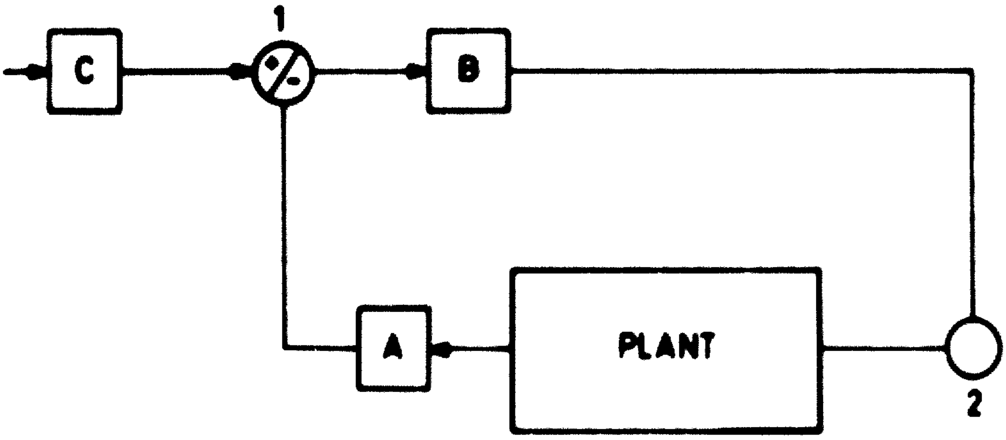

Figure 2. Diagram of an automatic control system: (A) measuring unit, (B) regulating-adjusting (control) unit, (C) input element: (1) comparison element, (2) final control unit

Practical application of automatic controls in the textile industry

Automation is at present in practical use, to a greater or smaller extent, throughout the textile industry, and the scope of its use increases continually.

Although spinning machines are rather difficult to control automatically, there is nevertheless a continual expansion of their degree of automation.

In the set of opening machines, a control for feeding individual machines with cotton fibre mass is applied. The principle of the control consists in maintaining the quantity of fibre in the machine within definite limits. Upward or downward variation of the fibre mass level affects the switching on or off of the pneumatic transporters or mechanical feeding devices. In this case, the simplest type of on-off controller can be used.

A rather similar type of control has also been used in woollen carding machines that have a "weight controller" that automatically weighs definite quantities of fibre and drops them onto the transporter periodically.

More complicated in action and containing all of the elements of the automatic control is the spinning controller used in ring spinning frames. Its task is to programme the control of the rotational speed of the propulsive motor and that of the spindles, depending on the phase of the winding of the yarn on the cop. This control ensures the tension stability of the yarn during ballooning and thus tends to decrease the number of thread breaks.

The conventional method of production of worsted yarn, for which a high degree of uniformity is required, demands the employment of a great number of plyings in the preparatory division, and that, in turn, requires a great number of passages through the machines.

In order to decrease the high costs of worsted yarn production, the manufacturers of textile machines are producing shortened machine sets that consist of equipment for the automatic equalization of the drawing sliver. The self-equalizing equipment that acquired recognition in wool-spinning is now employed to a great extent in cotton-spinning as well. These machines equalize the sliver on the basis of automatic change of the draft according to changes of thickness of the feeding layer. However, machines constructed by different firms are based on different principles.

Among the most generally used devices of this type may be included the Raper (United Kingdom) device, which acts on a mechanical principle used in the Prince and Smith (United Kingdom) drawing frame, an electrical device employed in Trmatex (Italy) drawing frames and hydraulic equipment applied in the OTO Melara (Italy) and SACM (France) drawing frames. In all these devices the actual specific weight measurement of the input drawing sliver is performed mechanically.

The measurement made in the Raper equipment is registered in the mechanical memory that adjusts the magnitude of the draft. In electrical or hydraulic equipment, the measurement result regulates the draft magnitude by the decelerating system. The need for decelerating devices is caused by the fact that measurement of the thickness of the sliver is performed before it enters the drawing field.

Experiments are being carried out on the use of radioisotope thickness meters to measuring sliver thickness in automatic equalizing machines. Such a measuring system is used at the drawing frame constructed by IVUT (Czechoslovakia).

In weaving mills, where almost all of the basic machine elements of automatic control can be found, automation is applied to a far greater extent than in spinning mills.

The sizing and drying units for warp threads deserve special attention. In the warp-sizing process, special attention has been given to the needs to maintain a constant tension on the warp, both during its passage through the machine and during winding onto the beam, to maintain a constant concentration and level of size in the size box and also to maintain a constant humidity of the dried warp.

Maintenance of a constant tension of the warp thread wound on the beam requires a proper control of the rotational speed. It is well known that, to obtain high quality of the warp beam, it is necessary to maintain a strictly defined and constant warp tension in each layer. According to the latest findings, this tension should amount to about 25 g per thread, regardless of warp yarn count.

A warp beam driven by a winding device should rotate at a speed sufficient to ensure that the threads will be wound with the required tension at a constant rate of feed of the dried warp. In other words, the product of linear winding speed and the total tension of warp threads should be constant. However, since the product thus calculated represents a power with which the winding device should work, the wattmeter that measures the actual power absorbed by the driving motor of this device is the measuring-unit component of the automatic control of the drive.

Considering the assumed minimum and maximum warp beam diameters the adjustment should make it possible to control the rotational speeds in range from 1 : 6. Other very important influences on warp quality are the final humidity of the warp and such parameters of the sizing agent in the size trough as concentration, temperature and degree of expression.

The only widely used system for the control of size concentration is that of Shirley. In this system, the amount of size fed depends strictly on the linear speed of the warp course, and the proper level of the size in the trough is adjusted by the level controller, which adjusts the quantity of the feed water used to dilute the concentrated sizing agent. The Shirley size-box is described in detail elsewhere in this series.[1]

Experiments are being made on the use of radioisotope meters to measure size concentration. It should be noted that the viscometers that were used in the past to measure the quality of the size were of little real value, since it has been proved that considerably different size concentrations can have the same viscosity, depending on the degree of mechanical dispersion of the size particles.

The trend toward automation throughout the textile industry has also influenced finishing and dyeing machines and equipment. The most important reasons for introducing automation into the finishing processes include the following:

General technological development;

The introduction of new fibres that require special finishing techniques;

The introduction of new dyestuffs, finishing agents and the like;

The elevation of the quality standards of textiles finishes; and

The general tendency to reduce production costs while increasing machine output.

At present, to a greater or smaller extent, almost all finishing machines have been automated. Moreover, among others, the following process parameters are automatically regulated:

The dye-bath, air, and steam temperatures;

The humidity of woven and knitted fabrics;

The level of the dye-bath;

The concentration of chemicals;

The tension of the fabric track;

The perpendicularity of the weft.

Temperature control

Automatic temperature control has been used in textile finishing of various kinds for many years. Considerations of technology and power supply have tended to

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[1] J. Żydło (1970) "Trends in the Development of Automatic Sizing Control in Connexion with the Intensification of Weaving Processes" in *The Łódź Textile Seminars 4, Weaving and Associated Processes*, United Nations, Vienna, ID/SER.D/3/4.

favour the introduction of automatic controls. This tendency may be illustrated by the fact that automatic temperature control of the dye-bath makes it possible to obtain the same dye toning, an optimal course of some operations and also a considerable saving of steam (sometimes as much as 30 per cent). Automatic temperature control has acquired significance especially during the last fifteen years, that is, from the introduction on a large scale of new finishing methods and new dyestuffs in the production of synthetic fibres. Processes such as dyeing in pressure dyeing apparatuses or by the Thermosol method would not be possible without automatic temperature control.

Automatic temperature control is most often used to maintain constant temperature during a process. Devices for this purpose have been in use for 30 to 35 years. The introduction of programme control was a great achievement that has made possible the maintenance of a prescribed temperature over a given period of time.

Automatic temperature control can be used with most textile finishing equipment. At this time it is used in winch dyeing machines for woven and knitted fabrics and in continuous multicompartment machines, in the last case, some individual compartments are supplied with their own control devices. They are also found in padding machines, particularly in the impregnation of woven fabrics with diastaphor (an enzymatic desizing agent) or napthol, in mercerizing machines, in pressure-dyeing machines in which temperature regulations are applied, in scouring machines for woven woollen fabrics (also programme temperature control), in the stabilizing parts of stenter frames (where the maintenance of air temperatures within a tolerance of 1° to 2°C is of great significance), in condensation machines, in calenders (in which high cylinder heat must be maintained at a constant level), and in cylinder driers and the like.

In general, it should be stated that use of automatic temperature controls is increasing. Lately, steam temperature control has also been introduced in agers, especially where steam flows within them through a perforated pipe. The temperature is controlled by the injection of water into the steam in the pipeline. Controls of these kinds may be included in the group known as self-operated controllers: that is, those in which the agent contained in the sensing element itself changes the manipulated variable, or to the group of controllers with auxiliary power agents, such as compressed air (servo-operated regulators). These devices also can be assigned to the group of controllers that have definite variable adjustments (two- or three-step controls) or to those that have infinitely variable adjustments (P, PI and PID controllers).

Humidity control in the drying process

For many years the attention has been attracted to the necessity of maintaining the humidity of dried woven and knitted fabrics on a definite level because, in practice, they are often overdried. Overdrying decreases the output of the driers and causes deterioration of the qualities of dried materials, especially of wool. Furthermore, too much steam is used, with a resulting increase in drying costs. Manual control of the condition of the dried material is usually insufficient, being restricted to deciding whether the material is still wet or sufficiently dry.

For at least 25 to 30 years, devices of several kinds for automatic humidity control have been in use. Some of these devices operate on the principle of measuring the dielectric constant of the fabrics, others on the principle of measurement of their electrostatic charge and still others on the principle of measurement of electrical resistance.

The first of these methods depends upon the dielectric constant (ε) of the fabric. After final drying, this constant has a value of about 2; when the fabric is wet this constant can have a value as high as 80, depending on the water content. This method gives very good results in estimating the humidity of fabrics of as constant as possible a surface weight (grams per square centimetre); it does not give correct results with fabrics of considerably differing weights. This difference of results is caused by the fact that the capacity of the feeler-condenser dielectric (that is, the fabric) depends on the humidity as well as on the weight of the fabric. Consequently, this method is very seldom used.

The second method consists in measurement of the static electricity charge of the fabric. This method has been little used because the magnitude of the charge depends not only on the humidity content but also on the speed at which the fabric passes through the machine. The charge measurement is performed in a contactless method by means of an electrostatic voltmeter.

A third method is widely used. It is based on the cross-resistance of the dried fabric. Since there is a logarithmic dependence of the electrical resistance on the water content of the fabric, the humidity change per unit affects the resistance change by one order; that is, by a factor of 10.

The electrical resistance measured according to this method depends to the greatest extent on the humidity content; to a lesser (but perceptible) degree, this resistance depends on many other factors, such as surface weight, the kind of fibre, the weave, the surface condition and the composition of the bath impregnating the fabric. All of these factors affect the precision of the measurements by ± 3 per cent in the case of cotton fabric and by ± 5 per cent with woollens. Consequently, the indications of devices for the measurement and control of humidity are in some degree relative. To obtain more accurate values, it is necessary to state, in an experimental way (for example, on the conditioning base) what humidities of definite assortments correspond with the indication of the measuring devices and to adjust the proper values in the controllers accordingly. It must be emphasized that a device for automatic humidity control does not remove irregularities of drying caused, for example, by non-uniform wringing or drying.

The development of the construction of driers has exercised a decisive influence on the design of devices for automatic humidity control. Driers of the older types (the so-called multilayer stenters) treat a great amount of fabric and therefore its passage through the drying chamber often takes as along as 10 minutes.

Modern driers are usually characterized by the fact that the fabric is fed into them in small quantities and passes through them rapidly (sometimes only 10 to 15 seconds). In these circumstances, the so-called "dead time" of the drier is reduced greatly, and the drier becomes more adaptable to automatic control. Devices for automatic humidity control are installed on the stenter driers (one-passage, duplex, multi-layer), on hot-air drying machines and even on cylinder driers.

It must be emphasized that the residual humidity of the fabric is a controlled variable. The rate of passage of the fabric is a manipulated variable and is changed to obtain the constant humidity of the fabric leaving the drier. Experiments on influencing fabric humidity by means of temperature changes in the drying air (for example, by varying the pressure of the heating steam in the heater or by changing the amount of exhaust air) yielded no positive results, primarily because the dead times were too long and the reaction very slow.

Since the speed of passage of the fabric is a manipulated variable, the basic condition of humidity control is to equip the driers with drive devices that permit infinitely variable speed adjustment. This condition has been really fulfilled in the construction of modern driers. The advantages obtained by the employment of automatic humidity control of the dried fabric are the following:

(a) Increase of drier output by about 10 per cent;

(b) Decrease of the per-unit consumption of heating steam, also by about 10 per cent;

(c) The possibility of obtaining proper humidities (for cotton, about 9 per cent, and for viscose fibre from 12 to 13 per cent) when additional finishes such as Sanforizing and crease-resistance are applied.

Control of the dye-bath level

An automatic level control is seldom used because a constant level is usually maintained by overflow of the excess dye-bath. Examples can be found, first of all, in padding machines where a constant rate of passage of the fabric through a padding dye-bath is of primary importance.

The dye-bath level can be regulated by acting on the solution inflow. The fabric passing through the boxes takes up a quantity of the bath proportional to its weight, speed and initial humidity. If the quantity of the solution thus removed is the same as the amount of inflowing solution, the level in the box (for example, in the washing machine) does not change.

A constant bath level can be maintained in either of the two following ways:

(a) By the installation of meter pumps whose discharge is directly proportional to the speed of the fabric run. The coefficient of proportionality can be adjusted according to the weight and humidity of the fabric and the required degree of impregnation with chemicals;

(b) By application of a control system that measures the bath level by means of an appropriate detecting element (feeler) that compares it with the required level and, in the case of discrepancy, sets in motion a pump or a metering needle.

An electrode feeler for level measuring cannot be used with solutions that produce froth, which can cause a short circuit of the sensor electrodes even when the actual bath level may be lower. In this case, float systems or pneumatic systems are more suitable for use as sensors. With them, measurement of the height of the liquid column in the trough is transformed into proportional air pressure that controls the operation of the pump or metering needle.

Control of concentration

In most textile finishing processes, treatments are applied during which the water used contains various chemical additives such as acids, alkalis, dyestuffs and salts. The necessity then arises to apply control devices in order to maintain the

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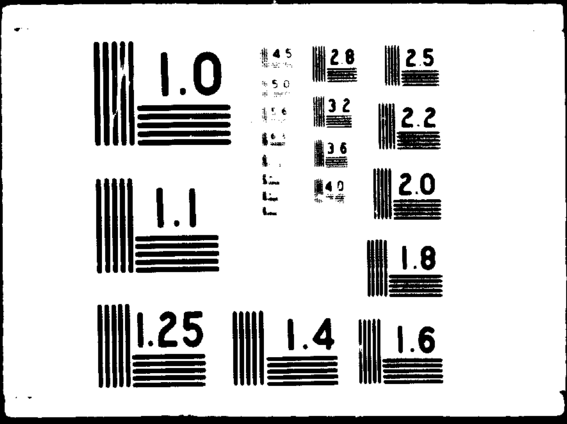

concentration of the solution on the level required for the given process so that disturbing influences may be disregarded.

Three types of concentration-control systems are in present use, as follows:

(a) A system whereby conductometric methods for concentration measurement are applied. These methods are based on the dependence of the conductivity of the solutions on their electrolyte content. Systems of this kind have been used successfully with solutions of hydrochloric acid, sulphurous acid, soda lye, sodas and the like.

(b) Systems that apply the photo-electric method for concentration measurement (the absorption coefficient of the light depends on the dye substance concentration in the solution). Devices of this type are used to control the concentration of dyestuff in a solution.

(c) Systems in which measurement is performed by an automatic titration device. These systems do not perform measurement continuously but in a periodic (impulse) manner.

All of these control systems influence the magnitude of the chemical influx in given process by means of automatically controlled valves or metering pumps.

The control of fabric tension in finishing

One of the principal demands placed at present upon finishing processes, and especially with fabrics made from artificial fibres, is the tensionless passage of the fabric, so as to minimize shrinkage.

The fulfilment of this condition requires appropriate changes in the construction of the machine and in the power transmission system. Such changes are especially necessary when the machine has a multimotor system of power transmission or when the process is performed in a system of two or more machines coupled in line.

The multi-box open-width washing machine is a good example. It has a multimotor drive, and the padder-drier unit is perhaps the simplest example of such a machine set. Between the successive pairs of squeezing rollers of the washing machine (each pair is driven by a separate motor), as well as between the padder and drier (each machine has its own driving motor), devices must be installed to correct changes in fabric tension caused by changes in the rotational speed of the next motor in the series.

In the examples mentioned above, the rotational speed of the next motor is usually changed; for example, the speed of the driving motor of the second pair of squeezing rollers is changed with respect to a box of a washing machine and to the driving motor of a padding machine. In a padder-drier unit, the driving motor of the padder is the leading one because, at a change of the speed of the set, only its speed is changed from the control panel or by means of automatic humidity controllers. In multi-box washing machines, this function is performed by the driving motor of the last pair of squeezing rollers (that is, those located at the delivery end of the machine). In multimotor driving systems, drives with compound direct-current motors in Leonard's system are used. There are only a few multimotor systems that use an alternating-current commutator motor. In two-motor systems, driving by Leonard's system is also used, as the asynchronous motors coupled with P.I.V. transmissions or with Behringer's hydraulic transmissions.

The rotational speeds of the various driving motors are controlled by properly balanced compensating rollers, which are activated by the horizontal and vertical movements caused by longitudinal tension on the fabric.

Compensating rollers cannot be used with very fine fabrics: for them, a sensor is used that acts without contact. In this method, the tension is noted at definite points in the length of the sag in loops of the fabric while it hangs freely. Variations, whether greater or less than the standard, are detected by changes in the flux of light falling on a photo-electric cell. These changes in the light flux change the current in the photo-electric cell, which in turn changes the rotational speed of the next motor in the series and thus the rate at which the fabric travels.

Straightening of the weft

During the finishing process, a change of weft position in relation to the warp often occurs, and bevels, bows and waves appear. Deformations of this kind can be removed, and this is usually done in a stenter drier with appropriate mechanical devices. Until recently these devices were controlled manually, which decreased the rate of fabric passage. In the last few years, however, devices for the automatic control of weft straightening have appeared that can operate at speeds unattainable with manual control.

There are three automatically controlled methods for eliminating weft deformation:

(a) With photo-electric sensing;

(b) With the sensing of plotted markings, which define the rectilinear track of the weft;

(c) With mechanical sensing.

The devices that operate on the principle of photo-electric sensing include two photo-electric cells that have diaphragms with pre-set gaps set between them and the illuminators. The gaps are set up at a definite angle (for example, +6° and −6°) in relation to the proper position of the weft.

When the weft appears to have shifted 6° from the normal position, one gap is completely covered and the other is strongly lighted, causing a signal, the intensity of which is a measure of the crooking of the weft. The photo-electric cells are placed on one side of the fabric and the illuminators are set out on the other side. The device is usually equipped with three heads, each of which is supplied with a pair of photo-electric cells. The six cells are spaced across the width of the fabric. The measured value of the weft deformation is thus obtained. An electronic deformation analyser can give four orders, namely:

(a) Arc to the front;

(b) Arc to the back;

(c) Right diagonal to the front;

(d) Left diagonal to the front.

Fabric through which light cannot pass can be supplied with markings of weft perpendicularity plotted in the form of points set at definite intervals. These points can be sensed by means of indicative sensors if they contain a ferritic powder, or by photo-electric cells if they are marked with brightly glittering dyestuffs. The sensor simultaneously controls the position of two points: one from the reverse side of the fabric, the second from the obverse side.

When a weft deformation (usually bevelling) appears, the device functions on the basis of a measurement of the time difference between the appearance of the first and the second points. An order sent by the controller then straightens the bevels.

The third mechanical method is employed in the case of fabrics led without the use of chains. In this situation, the weft deformation affects the warp deformation. For measurement of both the warp and weft deformations, a very sensitive sensing wheel can be used, the plane of which is set up according to the direction of warp threads on which it lies. The position of the wheel axis is registered on the potentiometer, which gives the proper orders to the device that straightens the weft.

The organization of repairs in the Polish textile industry

by

A. Znosko

The main duty of repair services in textile industry is to maintain the full efficiency of all buildings and plant equipment. Regulations concerning the authority and responsibilities of the repair services in Poland have been established.

Generally, the repair function in the textile industry may be divided into activities concerning machinery and production equipment and those concerning the plant buildings. This division is reflected in differences in organization.

In Poland, for the care of machinery, the method of periodical and standard repairs is applied. Buildings on the other hand are subjected to overhaul repairs. Methods for the repair of machinery and buildings have been codified into a System of Planned Preventive Repairs (SPPR).

The system of planned preventive repairs

This system includes all organizations and technical enterprises that have to do with protection, inspection, operation and repairs of buildings, grounds, and machinery. Preventive maintenance is performed according to a previously fixed plan. A system of this kind can ensure conditions for the maximal improvement of resources over as long a period of exploitation as may be technically and economically justified, and for the planned interrelation of repair and production activities.

SPPR has many advantages, the most important of which are the three following:

(a) It lays primary stress on the prevention and retardation of wear and tear.

(b) Particular attention is given, not to major repairs, but to minor repairs and to periodical and conservation repairs, since these are of prime importance for the proper maintenance of the plant and for the extension of periods of operation.

(c) It permits the planning of repair activities in connexion with the general economic programme of the plant.

SPPR is based upon scientific and technical principles and also on a set of rational, economic and technical indices. The actions and operations of this system are incorporated into suitable instructions and regulations concerning both exploitation and maintenance activities.

These regulations are entitled "Instruction for exploitation and repair action" and include the following elements:

(a) The manner of preparation for exploitation. and for the putting into operation, control and stopping of machinery and equipment;

(b) The service, maintenance and lubrication of machinery and equipment;

(c) Technical conditions of exploitation;

(d) The principles governing overhauls, minor and current repairs, and of control inspections. They determine the frequency of repairs, periods between repairs, the timing of a given repair, its range, the number of specialists needed in the repair crew, the list of needed spare parts and materials, and regulations for technical checking of the acceptability of the completed works;

(e) Guide-lines for the use of control and measurement instruments;

(f) The recording of repairs; and

(g) Regulations for work and fire safety.

The exact observation of these regulations permits the plant to operate without breakdowns and provides for the proper protection of machinery and its rational, economical and technical use.

Methods of repair

The three following methods are contemplated in SPPR: repairs after inspection, planned periodical repairs and standard repairs.

The method of repairs after inspection is the simplest of these. In the textile industry, it is applied only for buildings, water-supply and sewerage installations air-conditioning systems and, exceptionally, for some unusual machines about which insufficient information is available.

In this method, only the time of inspection and the size and composition of the inspection crew is planned. Generally, such inspections take place twice yearly. The inspection consists in the testing of particular parts, and the fundamental purpose is to determine the rate of wear and tear and to establish the range of repair work. Based on the findings, a suitable documentation is prepared and spare parts for the repair are procured.

The disadvantage of this method is that the range and time of repair are not planned in advance but determined only after the inspection. It is therefore the method applied mainly for buildings, where the determination of the range of repair and time required is rather difficult to anticipate.

The method of planned periodical repairs is a system of higher order. By this method it is possible to plan all repair work in advance and calculate its optimum timing and range. This can be done on the basis of knowledge of the operating characteristics of the machines and of the pattern of their wear.

The main feature of periodical repairs is that all repair work is dealt with in a planned period, called the overhaul cycle, which is defined as the time interval between two consecutive general overhauls. During this period, inspection, preservation and lubrication operations and repairs of various kinds are made at predetermined intervals and in a definite order.

The length of the overhaul cycle is determined by the permissible degree of wear of the parts and assemblies of the machine in question. The range of the repair must ensure the normal operation of the machine, at least until the next overhaul.

The application of the periodical repairs method makes it possible to draw up plans for repairs, for the purchase of spare parts and materials, for the planning of labour utilization and of financing. It also makes possible the rather exact determination of the scope and kind of repair shops needed and the interrelation of repairs with the productive activity of the plant. The primary advantage of the periodical planned repairs method is the possibility of complete preparation for the given repair and the avoidance of unplanned stoppages of the machinery and equipment.

This method is obligatory in the textile industry and is applied to all machinery and technical equipment except for machines of key importance, such as turbo-generators, the main power machinery and large production aggregates. With equipment of this kind, the method of standard repairs is used.

The method of standard repairs is characterized by exactly determined times of obligatory stoppage of a given machine and the execution of the determined range of repair work, irrespective of the actual condition of elements to be replaced. The repairs are made according to a previously elaborated technology, and the repair periods are established in a manner that will ensure that the wear and tear on individual machine parts will not exceed the permissible limits during the overhaul cycle, since the standard repairs method increases the use of spare parts. However, some of the elements replaced can be re-used, after suitable selection, in a subsequent repair.

The method of standard repairs has the advantage of reducing machinery down-time to a minimum and also permits the performance of all preparatory work before the actual repair.

Repairs made by this method are more expensive than those made by the method of periodical repairs, but the basic importance of some machines and equipment in manufacturing processes justifies this increase of costs. Also, the application of this method ensures the absolute continuity and reliability of machinery.

Kinds of repair and maintenance service

The following maintenance and repair operations are foreseen in SPPR: current maintenance, periodic inspection, current repair, intermediate repair and general overhaul (major repair).

Current (inter-repair) maintenance is the basic preventive operation. The currect organization of the maintenance service ensures a period of longer utilizability of equipment, lowers down-time for repair and maintains good machine performance. Current maintenance comprises the correct supervision of the machine, cleaning by the cleaning crew, changing of oil and other lubricants according to the special time-schedule by the lubricating crew, the supervision of the correct use of machine, regulation of mechanisms and elimination of minor irregularities of operation.

Periodic inspection work is performed according to the time-schedule. The causes of damage to machine elements and assemblies that are inaccessible to direct observation are determined. With suitable control and measurement instruments, the technical state of details is ascertained and the regulation and precision of their operation is tested. Inspection is performed without interrupting production, during technical stoppages, in the time between shifts or even on non-working days.

Current repair is characterized by small operations, such as the changing of a small number of worn parts and the regulation of mechanisms. Repair of this kind ensures normal operation during the period before the next overhaul. The lifetime of parts is equal to or even less than in the overhaul cycle. Current repair is performed during any normal stoppage of machinery.

Intermediate repair is the kind of planned repair that requires a partial dismantling of the machine. During such repairs, some parts and assemblies are changed so as to restore the precision, efficiency and productivity of the machine until the next general overhaul. The lifetime of the parts is the same as for the period between two intermediate repairs. Although the machinery is not dismantled completely, its operation must be interrupted.

General overhaul includes repairs within the major range of planned operations. The machine is almost entirely dismantled, and all worn parts and assemblies are replaced. This restores the efficiency and precision of the machine almost to their original levels. During the general overhaul, modernization may also be attempted. This means that not only technical wear but, when possible, obsolescence should be corrected.

The experience acquired with SPPR permits the introduction of additional technical and organization forms; namely, complex repairs and shop repairs.

Complex repair is characterized by dismantling the machine into assemblies that are convenient for repair work. Such repairs are previously prepared in the shop. After preparation on special regulation stands, such a rebuilt assembly is replaced in the machine as a unit instead of only individual parts. The early preparation of an assembly shortens the down-time of machinery. The system is applied at this time to some selected textile machines such as carding machines and roving and spinning frames.

Shop repair is performed in the textile industry in plants that have many machines of the same type or machines such as looms that are of small size and therefore may be transported easily.

In plants in which shop repairs are made, a number of reserve machines are required. A reserve machine is repaired in the repair shop, exactly controlled and then transported to the work-place. From the production point of view, this is one of the better repair methods, since the actual production stoppage covers only the time needed to disconnect the worn machine and bring in, set up and set in operation the repaired, re-painted, run-in and controlled machine.

After major or intermediate repair and after service testing, the machine is delivered to the head of the manufacturing department, with a record of delivery. This record contains the date, the personnel roster of the repair crew and an estimate of the cost of the repair. The receipt for the machine is divided into primary and definitive parts. The primary receipt records the repair quality and the mechanical properties of the machine before it is introduced into the production line while it is still accessible for any testing. The definitive receipt is completed after a determined time of production by the repaired machine without any damage and after it has produced a suitable amount and quality of its product. A supplementary control consists in the measurement of the power input.

Organization of repair and maintenance services

The principle of organization of repair and maintenance is uniform throughout the Polish textile industry and is based upon SPPR. Only the number of repair workers and the equipment of repair shops vary, depending on the size of a particular plant and the characteristics of its production and machinery.

Repair service organization is of a mixed type; that is, some of the operations are centralized, others are decentralized. The centralized elements include repair shops, major and intermediate repairs of machinery, and all repairs of buildings.

Manufacturing departments are responsible for the proper technical state of their machinery, for maintenance operations and for current repairs. The responsibility of manufacturing departments is relieved only when a machine is turned over, together with a transfer record, to the Chief Engineer for major or intermediate repair. The Chief Engineer is an inspection officer who controls the correct exploitation of machinery, its maintenance and the execution of current repairs. This officer is the chief of the repair service and bears the full responsibility for the maintenance of machinery, equipment and buildings in a proper technical state that will ensure the optimal operation of the plant.

The Chief Engineer superintends and bears responsibility for the proper functioning of the repair shop, the economical operation of the tooling and lubrication services, the acquisition of materials and supplies, the production and repair of spare parts and the proper exploitation of repair machines and construction equipment.

The repair service is divided into branches for management and execution. The management branch is divided into the six following ranges of operation:

(a) The Division for Planning Reports and Statistics maintains the file on equipment used for repair purposes, for planning on the basis of standards of annual and long-term repair programmes, for planning the modernization of machinery, for the elaboration of a time-table for repairs and for the planning of building repairs, reports and statistics.

(b) The Division for Repairs of Buildings is responsible for the continuous inspection of buildings, for the planning of current building repairs and maintenance, for the preparation of documentation for repairs, for the inspection of completed repairs of buildings, for acceptance of repairs, for the costing of repairs and for ordering building materials.

(c) The Division for Technical Documentation takes care of the archives of technical documentation for repairs of machinery and equipment, the execution of workshop drawings and catalogues of spare parts, the documentation for modernization and the documentation of instruments and their proper use.

(d) The Division for Spare Parts records the amounts and kinds of necessary spare parts, orders spare parts from producers, inspects existing stocks of spare parts, orders materials for the in-plant production of spare parts and prepares statistics on the use of spare parts in repairs.

(e) The Division for Technical Inspection is responsible for the inspection and co-ordination of intermediate and major repairs of machinery, the receipt of machines for repair, the technical receipt after repairs, the elimination of worn machines, the inspection of production machinery and of current

repairs in manufacturing departments, and for the analysis and recording of machinery breakdowns.

(f) The Division for Oils and Greases maintains the archives of lubrication regulations, new regulations of lubrication, standards for lubricant use, statistics of the use of fresh lubricants and the return of used ones, the inspection of supply of lubricants and of the work of the lubricating crew and the control of the lubricant quality.

The larger textile plants have both central repair shops and small shops in individual manufacturing departments. The latter deal exclusively with minor repairs of machine parts and current repairs. Central repair shops are small plants for the production of spare parts. Since they produce many different objects in short series, such shops must have universal equipment. Repair shops perform functions such as machining, bench work, heat and plastic treatment, welding, tin-smithing, materials storage and cutter-shop and tool-room operation.

The executive branch of the repair service is divided into the following five sections:

(a) The chief of the central repair shop is in charge of control workers, foremen and workers of different crews, a planning specialist, a tool engineer, a cost accountant and shop office workers.

(b) The wood-working and pattern shop executes all joinery work and pattern-making.

(c) The building crew includes masons, carpenters, roofers, painters and glaziers.

(d) Repair crews perform general overhauls and intermediate repairs of spinning, weaving and finishing machinery.

(e) The store-room for spare parts operates in close collaboration with the inspector of quality of spare parts obtained from in-plant production shop and by purchase.

The executive branch of the repair service also includes a Department for Modernization and Repairs. Its operation range is as follows:

Documentation of spare parts for older machines (that is, those produced before 1945);
Preparation of new catalogues of spare parts;
Establishing branch archives of documentation;
Co-ordination of the design offices of different plants;
Standardization of spare parts;
New production techniques for spare parts;
Testing of the wear of spare parts;
Establishing technical standards for the receipt and storage of spare parts;
Drawing up regulations for repairs, lubrication and exploitation of machinery;
Investigation of new lines for modernization;
Testing of prototypes of textile machines;
Establishing principles for the construction of new machines;
Testing of substitute materials and plastics;
Testing of anticorrosion materials;
Investigation of new improvements in repair methods;
Study of the economic effectiveness of repairs;
Investigation of new methods of organization of the repair service.

SOME PROBLEMS OF WATER SUPPLY AND WASTE-WATER TREATMENT IN THE TEXTILE INDUSTRY

by

T. Sędzikowki and E. Kwasik

Water in the textile industry

Water demand

About 69 per cent of the water consumed in the textile industry is used in production processes. About 6 per cent is lost, and the remaining 25 per cent is used about as follows: power supply, 15 per cent; drinking-water, 9 per cent; and miscellaneous, 1 per cent.

The water demand in different sections of textile industry varies widely. In spinning and weaving mills, water demand is slight and is used mainly for sanitary purposes. Great amounts of water are used in the washing, dyeing, bleaching and retting processes.

Water consumption also differs between plants, even when production processes and machinery are alike. Measurements of water consumption show that unit consumption (in litres or cubic metres per running metre or per kilogram) deviates considerably from mean values. The range of unit water consumption in various operations is shown in table 1. From the figures of this table and the production volume of a given plant, it is possible to estimate the total water demand for it. As the production of large textile plants ranges approximately from 100,000 to 250,000 running metres per day in the cotton industry, 5,000 to 25,000 running metres per day in the woollen industry and about 4,000 running metres per day in rayon-finishing plants, the water demand for these plants is 12,000 m^3/day, 5,000 m^3/day and 4,000 m^3/day, respectively.

The requirement for fresh water for feeding boilers in plants with dyeing and finishing departments is small, not exceeding 10 per cent of the production-water demand.

Quality requirements for water

The requirements for boiler water are analogous to those for boilers in other branches of industry. They depend entirely on the type of boiler used.

Water for use in finishing operations must meet only three standards. The actual requirements are the following:

(a) The water must not have too high a content of heavy-metals salts, as they

TABLE 1. CONSUMPTION OF WATER IN TEXTILE INDUSTRY PROCESSES[a]

	Water consumption	*Remarks*
Cotton industry		
Bleaching of yarn	110—220 litre/kg	Depends on method
Bleaching of fabrics	1,500—3,700 litre/100 m	Depends on method
Mercerizing	700—1,500 litre/100 m	Depends on method
Dyeing of fabrics:		
continuous process	1,200—1,250 litre/100 m	Depends on method and dyestuffs used
periodic process	1,200—5,000 litre/100 m	
Dyeing of yarn	60—200 litre/kg	Depends on method and dyestuffs used
Washing after printing	1,500—2,500 litre/100 m	
Generally	50 litre/m	For 1 running metre of fabric
Rayon and silk industry		
Dyeing of yarn	240 litre/kg	
Bleaching of fabrics	275 litre/kg	
Dyeing of fabrics in winch machines	175 litre/kg	
Dyeing in vats	1,000 litre/100 m	
Bleaching in vats	1,250 litre/100 m	
Generally	60—70 litre/m	For 1 running metre of fabric
Flax industry		
Retting	20—60 litre/kg	Depends on method
Wet spinning	5 litre/kg	
Bleaching of fabrics	200—450 litre/kg	
Dyeing of fabrics	150—240 litre/kg	
Generally	150—200 litre/kg	For 1 running metre of fabric
Wool industry		
Washing of loose wool	80—150 litre/kg	
Carbonization	130—200 litre/kg	

TABLE I *(continued)*

	Water consumption	*Remarks*
Washing of hair wastes in oval vats	525 litre/kg	
Dyeing of loose fibre	80—150 litre/kg	
Dyeing of combed wool	150 litre/kg	
Dyeing of yarn on cross cops	200 litre/kg	
Dyeing of pieces	150—290 litre/kg	
Washing of pieces	110—270 litre/kg	
Generally	250 litre/m	For 1 running metre of carded fibre
	350 litre/m	For 1 running metre of combed fibre

[a] The volume of waste water is roughly 90—100 per cent as great as total water consumption.

can cause discolouration of the fibre. In the water for bleaching, the iro content must be below 0.1 parts per million (ppm), and manganese conten must not exceed 0.05 ppm. The limitations for drinking-water are stricter 0.3 ppm and 0.1 ppm for iron and manganese respectively. In water fo dyeing, the content of these metals may be as high as 1 ppm.

(b) The water must be soft. Total hardness must be kept within the limits of to 2 milligram equivalents (mval) per litre. In some cases the hardness o water may be higher—up to 4 mval/litre. Absolutely soft water is unsuitabl for finishing purposes, since the soap used would be too strongly absorbe by the fabric, which would necessitate long rinsing and consequently lowe machine productivity.

(c) The water must be free from mechanical contaminations (suspended matte and micro-organisms, and it should not be discoloured. However, littl attention is paid to this last consideration.

It is thus clear that the requirements for water purity in textile industry ar more stringent than those for drinking-water. Nevertheless, for some productio operations the requirements can be considerably lower. It has been shown in som investigations that water with a biochemical oxygen demand (BOD) of even 50 t 70 ppm may be used with good results for leaching acid washing and rinsing fror acid in the cotton-bleaching process. Also, for retting, surface water with a hig content of organic matter (BOD of more than 50 ppm) can be used.

This entire problem is presently under detailed study in connexion with th secondary utilization of polluted waters.

Methods of water purification

In order to attain the above-mentioned requirements for water, suitabl arrangements must be made. Their nature depends upon the quality of raw wate Subsoil waters will usually require softening and removal of iron. Coagulation wit aluminium sulphate and rapid filters are applied to surface waters. Boiler-feed water is softened by liming, lime-and-soda treatment, and by ion-exchange. Generally, the methods used are the same as in community waterworks and in other industries.

Waste water

Quantity and quality of textile industry wastes

The problem of waste water from textile industry is rather complicated, since this industry uses a great variety of raw materials, intermediate products and chemicals. Methods of production also vary widely.

As noted in the footnote to table 1, the quantity of waste water discharged into sewerage per production unit is roughly from 90 to 100 per cent of total water consumption. An important fact is the flow of waste waters caused by different finishing machinery and technology applied is irregular. The same machinery in the same plant can produce different waste flows when different dye-stuffs are used. Similarly, each change in the number of machines will change the amounts and composition of waste waters.

Generally, the hour-variability index[1] of waste waters exceeds 2, and in small plants this index may be considerably greater. The flow rate varies with rather great frequency; for example, it may be that the greatest volumes of waste water are discharged only once per shift, once per day or even once in several days. Evaluation of the inequality of waste water flow requires either the detailed analysis of all production operations based upon the plant project or the measurement of flow rates.

The qualitative characteristics of waste water are variable to a great extent and, even in the same industry branch, depend on the dye-stuffs and raw materials used, their ratios and the type of machines that are employed. Table 2 contains a summary comparison of limit and mean values of waste contaminants of water in the wool, cotton and rayon industries. Generally, these concentrations vary within broad limits for different plants.

The evaluation of the quantity and quality of waste waters must be made in close connexion with production analysis and the chemicals and production processes used, and must be based upon the plans for a new plant project or examination of an existing one. For existing plants suitable measurements and chemical analyses must be made, and for plants in the project stage, the characteristics of waste water from a similar existing plant can be considered.

Requirements for waste waters, depending on the means at their disposal

Waste water from a textile plant may go into a community sewerage network or directly into a river. The requirements for sewage quality are different in these two cases. The necessary pre-treatment condition of the waste water determines the size of a suitable sewage plant.

Discharge of sewage into a sewerage network

In this case, in addition to characteristics of the waste waters from a given plant, at least the approximate quality data of sewage in the municipal system upstream

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[1] The hour-variability index (I) is the ratio of the maximum volume (V_{max}) to the mean volume (V_{mean}).

TABLE 2. CHARACTERISTIC CONCENTRATIONS OF SOME CONTAMINANTS IN WASTE WATERS FROM WOOL, COTTON AND RAYON INDUSTRIES

		Wool			*Cotton*			*Rayon*		
Contamination	*Unit*	*min.*	*max.*	*mean*	*min.*	*max.*	*mean*	*min.*	*max.*	*mean*
Temperature	°C	16.0	65.0	33.9	7.0	85.0	26.0	14.0	60.0	29.00
Reaction	pH	4.6	11.0	—	2.0	12.5	—	2.5	12.3	—
Oxidizability (O_2)	mg/litre	12.8	4,080.0	238.8	24.2	7,440.0	511.9	16.0	1,200.0	280.80
BOD_5 (O_2)	mg/litre	20.4	3,600.0	372.0	17.0	9,400.0	461.5	16.0	892.0	298.60
Sulphate (SO_4^{--})	mg/litre	40.0	1,608.0	320.5	27.0	817.0	159.4	22.4	662.0	142.30
Chloride (Cl)	mg/litre	20.0	694.0	226.6	7.0	1,750.0	174.6	7.2	2,761.0	166.10
Nitrogen (N)	mg/litre	0.0	60.2	18.5	1.4	64.4	14.3	5.1	96.0	49.70
Detergents	mg/litre	0.2	50.0	5.2	2.0	12.4	7.0	1.0	4.4	2.93
Fats	mg/litre	205.0	2,981.0	1,403.0	—	—	—	—	—	—
Sulphide (H_2S)	mg/litre	0.0	159.0	16.6	0.0	48.9	0.5	0.0	36.7	5.27
Chromium (Cr^{+6})	mg/litre	0.0	7.6	1.3	—	—	—	—	—	—
Residue after evaporation	mg/litre	316.0	14,215.0	2,774.0	340.0	51,396.0	2,775.0	274.0	3,449.0	1,118.00
Suspension	mg/litre	8.0	9,515.0	713.0	10.0	12,512.0	297.5	10.4	1,002.0	118.80
Alkalinity	mval/litre	2.2	92.0	7.9	0.7	102.5	25.6	0.5	38.0	6.80

from the wastes inlet must be known. This is necessary in Poland, because permissible concentrations of wastes, when mixed with a given industrially polluted water, have been set by law. Therefore, otherwise identical plants must deal with their wastes in different ways, depending on the size of the municipal sewer. The maximum permissible values of some contaminants in communal sewers are shown in table 3. Sewage of these kinds may be treated in a biological sewage plant. However, the legal limitations do not necessarily ensure the correct functioning of the biological sewage plant. Consequently, industrial wastes must be suitably treated in the textile factory. Nevertheless, such treatment is not always possible or economically justifiable. In arguing in some cases against the planning of a local sewage-treatment plant it may be stated that:

(a) Waste water from the cotton industry does not interfere with the process of biological treatment, even when its amount is considerable in comparison with normal sanitary sewage. In some cases the ratio of cotton industry wastes may be 95 per cent of the total sewage. When sulphur or aniline dyes are used, the ratio must be lower. When the plant is not far from the municipal sewage-treatment plant, because of the fluctuation of pH values and the possibility of there being a toxic compounds content, a suitable equalization of wastes composition may be effective.

(b) Waste water from the wool industry is only rarely free from chromium and considerable amounts of sulphides and fatty compounds. They can therefore be deleterious to biological sewage treatment. The ratio of wool waste water to total municipal sewage must be low; in some cases only 2 per cent is permissible. If the ratio is higher, the wastes must be pre-treated to equalizing its composition and to remove noxious compounds.

(c) Waste water from the flax industry, when it flows off at a uniform rate, may safely be accepted into a community sewage-treatment station. However, the fact must be taken into account that high concentrations of organic matter in retting wastes may essentially influence the size of the municipal sewage-utilization plant.

(d) Waste water from the rayon and silk industry may be treated similarly to that from cotton plants.

TABLE 3. MAXIMUM PERMISSIBLE CONCENTRATIONS OF CONTAMINANTS IN SEWAGE

Contamination	*Unit*	*Maximum value*
Biological oxygen demand (BOD_5), expressed in oxygen units (O_2)	mg/litre	700.0
Suspension	mg/litre	330.0
Chloride (Cl)	mg/litre	350.0
Magnesium compounds, expressed in MgO units	mg/litre	300.0
Sulphate (SO_4)	mg/litre	300.0
Phenols	mg/litre	40.0
Methanol	mg/litre	15.0

TABLE 3 *(continued)*

Contamination	*Unit*	*Maximum value*
Detergents	mg/litre	10.0
Carbon sulphide (CS_2)	mg/litre	5.0
Sulphide (S)	mg/litre	3.0
Cyanide (CN)	mg/litre	1.0
Heavy metals (Ag, As, Cd, Cr, Cu, Hg, Ni, Sb, Zn) — global	mg/litre	1.0
Zinc (Zn)	mg/litre	5.0
Nickel (Ni)	mg/litre	25.0
Chromium (Cr)	mg/litre	0.2
Fats and greases	mg/litre	50.0
Inorganic salts	mg/litre	1,000.0
Reaction	pH	6.5—9.0
Temperature	°C	35.0

Discharge of sewage into rivers

In Poland, rivers used for the disposal of waste water are divided into four classes by law, depending on the utilization of their water and specifying the maximum permissible contents of contaminants. The maximum values concern the mean low-water flow of the receiving river and are valid for the dilution ratios of waste waters from 1:6 to 1:20. Other ratios are determined for special conditions. Industrial waste water must also meet additional requirements. The permissible concentrations in Poland of contaminants in rivers and in waste waters discharged into them are shown in table 4.

It can be seen from this table that the requirements are so high that, as a rule, effective treatment of sewage is necessary; 80 per cent removal of BOD and chemical oxygen demand (COD) must be reached.

Methods for the treatment of waste water

In the treatment of waste water from the textile industry, the three following methods are generally applied:

(a) Mechanical (physical) treatment, which consists of the elimination of floating particles, fats and quickly settling suspensions. Mechanical treatment requires devices for equalizing the quantity and the quality of waste water (retention tanks).

(b) Chemical treatment consists in the elimination of colloidal particles and dissolved components, mainly inorganic but also some organic ones.

(c) Biological treatment for removal of colloids and dissolved organic substances.

TABLE 4. SOME MAXIMUM PERMISSIBLE CONTAMINATION VALUES OF RIVERS DURING MEAN LOW WATER FLOW AND OF INDUSTRIAL WASTES DISCHARGED INTO RIVERS

(in dilutions from 1:6 to 1:20)

	Maximum values in rivers				
Contamination	*For basic use*	*For municipal use*	*For salmon fisheries*	*For agricultural use*	***Maximum values in waste waters***
Temperature (°C)	26	26	20	26	35
Residue after evaporation				1,200	
Suspension	30	20	10	30	60
Smell (plant smell scale, 1—6)	1—6	3	1—6	1—6	
Colour	Natural	Natural	Natural	Natural	100
pH	6.8—9.0	6.8—9.0	6.8—8.5	6.8—9.0	5.0—9.0
Oxygen	Above 4	Above 4	Above 5	Above 4	
Total alkalinity (mval/litre)	Above 0.6	Above 0.6	Above 0.6	Above 0.6	1.0
BOD_5	8	4	4	8	30
Oxidizability	30	20	20	30	80
Decay time (days)	Above 5	Above 5	Above 5	Above 5	
Chloride	—	250	250	400	2,500
Sulphate	—	50	50	250	500
Organic nitrogen	2	2	2	2	
Nitrate	0.1—3.0	0.1—3.0	0.1—3.0	0.1—3.0	1—13
Ammonia	2	2	2	2	
Iron	—	1	0.3	—	5
Zinc	0.7	—	0.02	0.7	1
Manganese	—	0.1	0.1	—	1
Chromium (VI)	0.1	0.05	0.05	0.1	1
Chromium (III)	0.5	0.5	0.5	0.5	1
Silver	0.005	0.005	0.005	0.005	1
Copper	0.1	0.1	0.1	0.1	1
Phenols	0.02	0.005	0.005	0.02	1
Oils and fats	No visible film	No visible film	No visible film	No visible film	30

Both chemical and biological treatments can be successful only when the waste water is equalized in quantity and quality and gross contaminations are removed from it. Therefore, such treatments must follow mechanical treatment.

The water-treatment devices in general use are well known, so discussion here is limited to only some of the problems that concern their proper size.

Since the sewage produced by the textile industry contains only small amounts of quickly settling suspensions, preliminary sedimentation basins are not used. The first step in the treatment of sewage is screening through fine racks. For wastes from the woollen industry, mesh screens and aerated grease-removal tanks are used. The most important problem of mechanical treatment is the calculation of the size of retention (equalizing) tanks. The proper size of the retention tank must ensure the equalizing of each important polluting agent, mainly: temperature, alkalinity or acidity (pH), free chlorine, sulphides and sulphates. It must also permit the continuous removal of suspensions or ensure agitation to prevent sedimentation.

Generally, the capacity of retention tanks permits a retention time of 3 to 12 hours, depending on machinery volume and the assortment of dyestuffs.

Retention tanks are either circular (Dorr type), with a mechanical agitator, or rectangular, with aeration in a ratio of 3 to 5 m^3 of air per 1 m^3 of sewage. They are equipped with an effluent weir or a floating overflow tube.

Chemical treatment consists in the coagulation of sewage with ferrous sulphate, lime-water and chlorinated lime. Sewage from the wool industry is often acid and must be treated first with lime and then with the addition of ferrous sulphate. The amount of the last must be limited, as this compound causes a rapid increase in the sulphate content of the effluent. Coagulation produces a volume of precipitate (sludge) equal to 3 to 15 per cent of the total sewage volume. The precipitate is highly hydrated, containing up to 99 per cent of water. The precipitate from dyeing wastes can be quickly dehydrated: it can be disposed on sand filters even in a 1-m thick layer. Filter presses work rather poorly, because the filtering cloth very soon becomes clogged.

Biological treatment may be applied to sewage from cotton bleaching. The activated-sludge method or biological beds without additional nitrogen-phosphorous food are used. The rate of BOD removal is from 10 to 15 per cent lower than in the case of sanitary sewage.

Possibilities for the secondary utilization of polluted water

Secondary utilization of polluted water is discussed in connexion with water deficiency in some regions. Economic analysis has proved that cost of water is, in most cases, less than 2 per cent of total production costs. Therefore, secondary utilization of water in the textile industry can be considered only in regions especially lacking in it, where this factor might limit production volume, or cases where the requirements for waste water are very high. In the latter case, economic considerations may be secondary.

The greatest possibilities for secondary water utilization are in the cotton, flax (retting) and silk industries. Systems whereby waste water from some operations may be re-used for others are best. Such a system would not require desalting of water or periodical exchange of all water. However, the removal of concentrated salt is necessary in a closed water cycle, and this involves the use of electrodialysis, reverse osmosis or ion-exchange methods, which complicates the problem.

Present investigations of secondary utilization of waste water from cotton bleaching after biological treatment and of wastes from the retting of flax and hemp after aeration give positive results. These investigations also prove that the requirements for water used in the textile industry are often too high; in many initial finishing operations, water with a relatively high content of both inorganic and organic matter may be used.

It would appear that some opinions on the requirements for water in the textile industry should be revised. Such changes of opinion may influence the further development of systems for the secondary utilization of polluted water in the textile industry.

PROBLEMS OF THE AUTOMATION OF CLOTHING PRODUCTION

by

W. Więźlak

The direction of development of clothing production and an appraisal of its technology

The clothing industry is still based on traditional technological principles that evolved during the nineteenth century. This technology consists in the mechanization of hand sewing and the division of the sewing process into a series of separate technical operations that can be executed by non-skilled workers. Because of the complexity of these operations, most of them are performed manually or with the aid of lock-stitching machines; that is, by combined machine and manual methods. The introduction of special machines has facilitated, in a certain degree, a reduction in the number of manual operations, but the rather complex construction of clothing products, and specifically of outer garments, does not permit the effective utilization of machines that depend for their efficiency not only on the speed of the sewing tools, but on the time required for auxiliary operations.

The time needed to perform these auxiliary processes, which constitute the majority of the technical operations, presents a serious hindrance to the further development of mechanization of clothing production; the strictly mechanized production time is only 14 per cent of the total.

In other domains of technique, the development of production methods has led, in the leading producing countries, to the highest forms of technological progress, that is, to automation, and other countries are entering this new phase of industrial evolution. However, not all fields of production are adaptable to automation, despite the existence of objective circumstances favourable to it, such as a relatively high level of the theoretical science of automation and the actual productive possibilities of automatic systems of process control. The primary obstacle in this respect is the still low degree of development of areas of production in which manual labour continues to play a large part, as in the clothing industry. The construction of machines that attempt to simulate human actions requires intricate patterns of mechanical performance, thereby raising the cost and minimizing the efficiency of such equipment. For this reason, many major enterprises that produce sewing machines (for example, both Singer and Reece in the United States, and Dürkopp in the Federal Republic of Germany) are rather sceptical about the introduction of automation into the clothing industry. It is therefore necessary to analyse the present methods of production and to appraise the real possibilities of automation in this field. This in turn requires analysis of its productive processes and of their fundamental part; namely, the technical operations.

The technical process, considered as a complex of actions directed toward production, may have a complex structure. It usually represents a set of operations of different kinds; that is, dissimilar ways of using productive tools on the workpiece. In determining the percentage share of operations of different kinds, higher or lower degrees of the technical process may be distinguished. The more prevalent the higher classes of operation are, the more receptive to automation the given process will be and, consequently, the more economically effective its automation will also be.

According to the manner in which a given tool acts upon the treated object, technical operations may be divided into three classes:

In the first class there is the needling operation of the tool on the treated workpiece. In this class of operations may be included all that are executed with an ordinary lock-stitching machine. In this class of machine work, the workpiece must be free to be shifted in space with regard to the three co-ordinate axes X, Y and Z.

The second class includes operations characterized by the linear action of a tool on the workpiece. Here belong various cutting actions, for instance the cutting-out of various small details, cutting along determined lines, measuring, bending and the like. The transporting device must shift the workpiece with regard to the two co-ordinate axes X and Y.

The third class includes operations in which the tool works on the surface of the workpiece, as in pressing and bending. In operations of this kind, transport is carried out along a straight line.

When analysing the traditional technical processes, classified in the above-mentioned manner, it can be seen that the most important of them may be assigned conveniently to the first class. These operations consume more than 90 per cent of the processing time of a workpiece. It thus follows that, in introducing automation into a production process that is characterized by the above-mentioned structure, the prime necessity is to design transporting links that can deal with operations of the first class. This possibility, although fully practicable under present technical conditions, is not sufficiently effective. An aggregate of apparatuses and mechanisms to replace manual work would feed an adequate supply of workpieces into the machine and provide appropriate transport during the sewing, in accordance with the technical programme. The process itself should be performed by properly controlled sewing devices. The aggregate would bring about co-operation between the transporting link and the sewing link, this co-operation being regulated by a special commanding device that operates in accordance with the controlling programme, ensuring the regular performance of both. Human participation would be confined to putting the aggregate into operation, shutting it down and servicing it. The ideal scheme of such a device (a monohead sewing automat) is diagrammed in figure 1.

The productivity of such an automat would depend on two links: the transporting link and the sewing link, both of them operating on the principle of reproducing human actions and those of sewing machinery. Increase of the efficiency of the automat may be achieved only through acceleration of the speed of action of the two essential links, and there is little hope that the productivity of such an automat would greatly exceed that of a man operating a sewing machine. On the other hand, the cost of the automat would be greater than that of a sewing machine and would be increased still further by the costs of the transporting, controlling and command links. In consequence, the productivity of an automated aggregate of this type is rather doubtful.

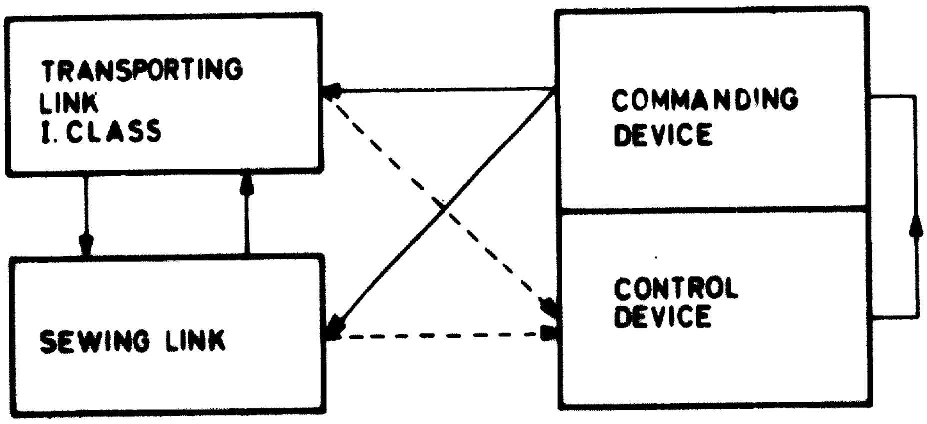

Figure 1. Diagram of an ideal monohead sewing automat

However, there are some other methods of increasing productivity without changing the basic process (class of operation). An increase in the productivity of an automat may be produced by connecting some operations, by the simultaneous performance of some of them by the sewing links or by performing an operation in parallel on a number of workpieces. The first solution would lead to an example such as that shown in figure 2. With this scheme only the construction principle of the sewing link is changed, while the remaining links remain as before. However, the connexion of some operations and their simultaneous performance leads to a complicated kinematic sewing link, where it is difficult to combine more than three operations, as for instance, sewing together a double two-line stitch and overcasting the edge.

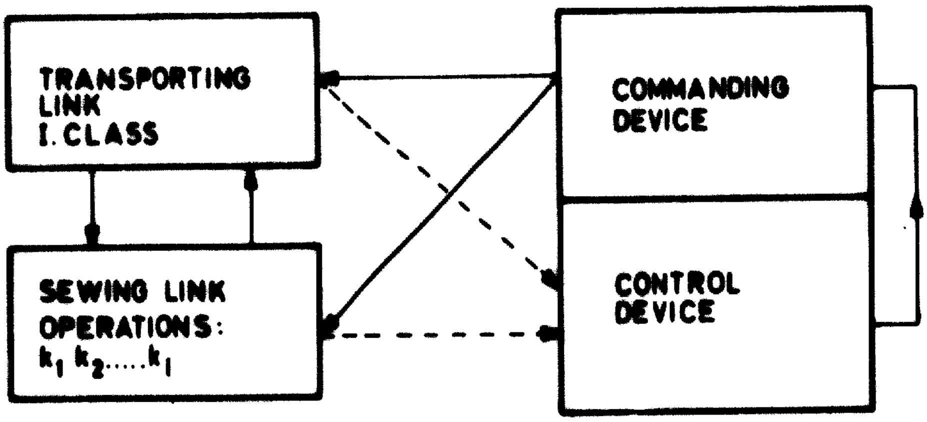

Figure 2. Diagram of an ideal multioperational sewing automat

A complicated scheme is also characteristic of the transporting link which, as in the first design, sets the workpiece in motion with regard to the three co-ordinate axes (operation of the first class). In consequence, the entire construction has a very complex kinematic layout, and the production costs of such a mechanism may strongly influence the feasibility of its industrial application.

For in-parallel operation on a number of workpieces, as shown in figure 3, there must be two or more sewing links combined into a set, which should be of a reasonable size. A good example would be a set for sewing the edges of three punched holes. Obviously, the cost of such an aggregate would be high, since it would include that of the basic machinery as well as that of the sewing links. In all three of the solutions discussed above and illustrated in figures 1, 2 and 3, the transporting, commanding and controlling links should be very much alike, and their cost should be considered as a constant.[1]

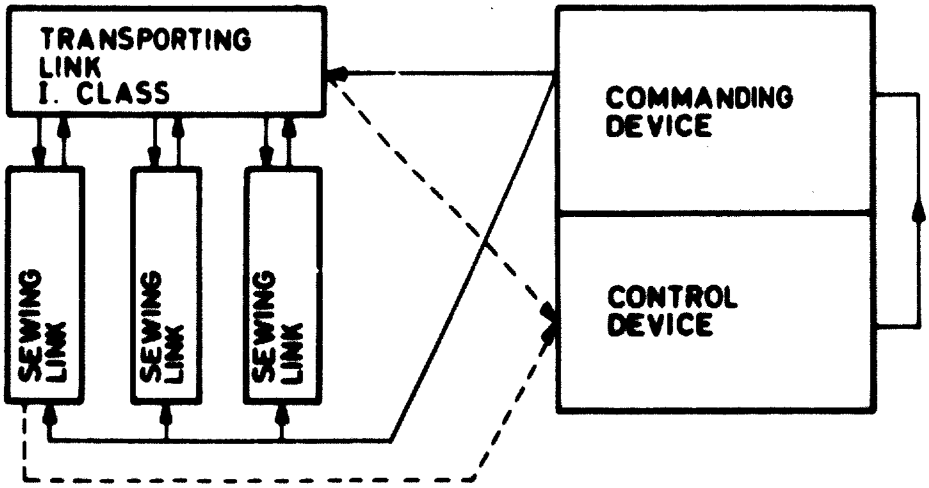

Figure 3. Diagram of an ideal multihead sewing automat with three sewing links

Analysis of these three construction schemes leads to the presumption that automation of clothing production may be accomplished in two different ways:

(a) By the construction of multi-operational machines (figure 2) or of sewing sets that combine, in parallel, two or more modern, automatically controlled sewing machines (figure 3);

(b) By the introduction of new technical methods for producing clothing; for example, by the use of machines designed for adhesive bonding or welding.

There appear to be other possibilities of intensifying the work of the sewing machines, although modern construction of these devices permits speeds from 5,500 to 7,000 stitches per minute. Some important reserves of production capacity may be gained by the elimination of technically needless stoppages and by the practical exploitation of the rated speed of the machines. The actual utilization of sewing machinery speed, as appraised on the coefficient of speed (the ratio of effective to nominal speed) is usually low, sometimes being as small as 15 per cent, and rarely exceeding 70 per cent. It is therefore necessary to analyse new ways of joining threads and to appraise their usefulness in the construction of automatic sewing aggregates. First of all, all machinery that sews with the lock-stitch or that performs double-thread chain-stitching should be studied, since these two types of stitching are used for many different articles and may be mutually interchanged without detriment to the quality of the product.

Although seams made with the double-thread chain-stitch are susceptible to stretching and are relatively easy to unsew, their great strength guarantees good seam quality. An additional advantage of chain-stitching machines is their low incidence of

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[1] Commanding and controlling devices are usually electronic and of standard construction; their cost can be taken as a constant. The cost of a transporting device will depend on the degree of its complexity, but this may be estimated approximately and will be constant for a given type of operation.

stoppages caused by the need to replace the bobbins and less damage to the sewing threads during stitching. This last feature is of especial importance to the technician, as it may, in a great degree, reduce breakage of the sewing threads. In consequence, the wider use of this stitch may increase the productivity of sewing automats.

The testing of the threads used in sewing machines is an important subject of laboratory research in industrial research institutes throughout the world. In Poland, a great deal of such research has been conducted for many years, especially as regards the testing and appraisal of the mechanical wear on threads and the technical appraisal of their properties.

Some technical aspects of machine sewing

The findings of tests made in the Clothing Department of the Łódź Polytechnic School permit the statement that the operational strain on the threads in the sewing machine is relatively heavy and that during the sewing process a thread is subjected to great wear and tear, with the result that its mechanical properties, as well as its structure, may be altered. In the extreme cases, the threads may be destroyed completely, as when an unfavourable layout of the tensions and loads applied to the threads causes convergence of their weakened portions, which may cause them to break.

The destruction of threads during the sewing process occurs for many different reasons. They may be divided into the following groups:

(a) The nature and technical condition of the sewing machine, such as its way of forming the stitch, the characteristics of its components and the condition and working precision of the mechanisms and of their surfaces;

(b) The technical parameters of the sewing machine include the speed of sewing, the number of layers of fabric sewn together, the quality of the textile being sewn, the density of the stitch, the static and dynamic tensions on the threads, and many other factors;

(c) The technical properties of the sewing threads, such as the resistance of the threads to the cyclic and dynamic stretching loads, the action of the twisting and untwisting forces, resistance to abrasion, resistance to heat, stiffness and very many others.

To put it another way, it could be stated that, in the greater number of cases in the contemporary technology of clothing products, the sewing thread should be selected carefully, taking into consideration the types of machinery that will be used and the technical parameters of treatment. For this reason the group of properties of threads that determines their suitability to form joinings under the specific technical conditions of machine operation may be designated as the technical properties of the sewing threads.

Obviously, these properties of threads do not and cannot be the only criteria for their selection; equally important are their specific properties, as determined by requirements that do not fall within the scope of this report.

Experiments have been made in which various operational strains on sewing threads were compared, using both lock-stitching and chain-stitching machines. It was found that the operational strains on the sewing thread in lock-stitch machines are far heavier than those existing in chain-stitching machines. In other words, on a lock-stitching machine the needle thread is subjected to greater and more numerous tensions and abrasive forces than the bobbin thread.

In the sewing-up of fabrics woven from synthetic yarns, an additional heating of the needle occurs. This phenomenon has been partly overcome by the application of well-known cooling methods. In this series of tests only the relative effectiveness of various systems of needle cooling was appraised.

Characteristics of the dynamic loads that cause stretching of threads

The fundamental characteristics of the dynamic stretching loads on threads during sewing can be determined with tensometric methods, that is, recording the incidence of tension on the threads with the aid of an oscillograph. A typical oscillogram showing the thread tension in the lock-stitch sewing machine is shown in figure 4. Analysis of this oscillogram readily reveals that the thread receives the greatest impact when the main machine shaft turns about 30°. The magnitude of the stroke may change to a great extent, but under the most unfavourable conditions of operational strain on the thread it does not exceed the value of 700 gram force units (G). Under these conditions it should be accepted that the rise and damping (attenuation) of the load occurs at a speed of 700 G per microsecond when the machine is operating at 5,000 rev/min.

Figure 4. Oscillogram of thread tension in the lock-stitch sewing machine

The frequency of these tensions (loads) equals the speed of the main shaft of the machine, since during one revolution of the main shaft the thread receives only one maximal stroke (approximately 80 Hz).[2]

The magnitude of the maximal dynamic tension of threads depends proportionally on their static tension (figure 5). Nevertheless, certain difficulties are

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[2] Some other local increases of dynamic tension may occur within a working cycle of the machine, but these will be considerably less than those described here.

associated with the magnitude of the static tension of the threads. In our research the static tensions were determined by the tensometric system, measured as machine speed approached zero.

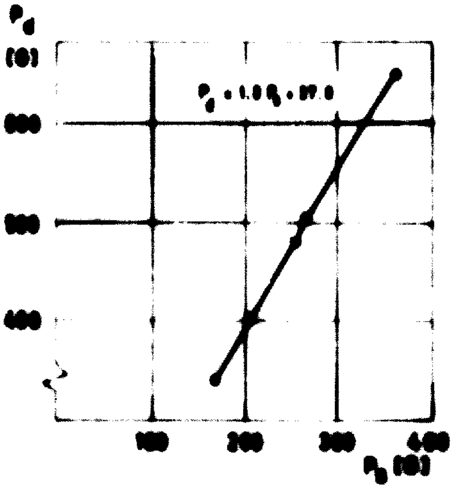

Figure 5. Interdependence between the static tension (P_s) of a thread and the maximum value of the dynamic tension (P_d) expressed in gram force units (G)

It should be stressed that, for the proper formation of a stitch, the static tension of the needle thread must be equivalent to the defined tension of the bobbin thread. The interdependence between the static tensions of the needle and bobbin threads is illustrated in figure 6, which demonstrates that the tension on the former is far greater than that on the latter.

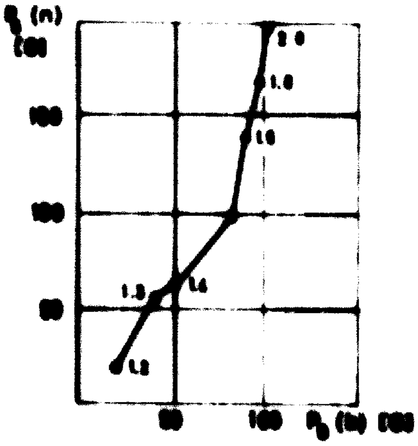

Figure 6. Interdependence between the static tension on the thread on the needle ($P_s(n)$) and that on the bobbin thread ($P_s(b)$) expressed in gram force units (G)

Comparison of the oscillograms of the lock-stitch sewing machines (figure 4) with those executed for the double-thread chain-stitch sewing machines (figure 7) permits the statement that substantial differences exist between the runs of these tensions.[3] These differences consist in the change of the lesser value of the maximal tension of the threads in the chain-stitch sewing machines performing double-thread

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[3] In figure 7 it can be seen that the first line characterizes the magnitude of tension on the needle thread, whereas the second line registers changes in tensions of the bobbin thread. The acute angles along the bottom of this oscillogram symbolize the direction of rise of the curves, since their courses have been reversed to facilitate their recording.

stitching, as compared with lock-stitch sewing machines. There are certain analogies consisting in the fact that the tension on the needle thread is about double that on the catcher thread. The absolute value of the tensions observed does not exceed 500 G (gram force). Needle thread tensions rise threefold in the course of one working cycle of the machine, whereas the tension remains nearly constant on the bobbin thread throughout almost the entire working cycle, running down to zero during the period of throwing of the previous loop of the needle (120° + 130°) and while the needle leaves the cloth. It follows that, in the chain-stitch machine, the needle thread is not subjected to as great changes of speed as in the case of the lock-stitch sewing machine. Greater changes in speed may be observed in the case of the bobbin thread, which is subjected to the influence of a single stretching impulse during the pulling (drawing) of the thread. The peak occurs at 25° of shaft rotation. Generally speaking, the variation of the run of dynamic tension in chain-stitch sewing machines operating with a double thread is less marked.

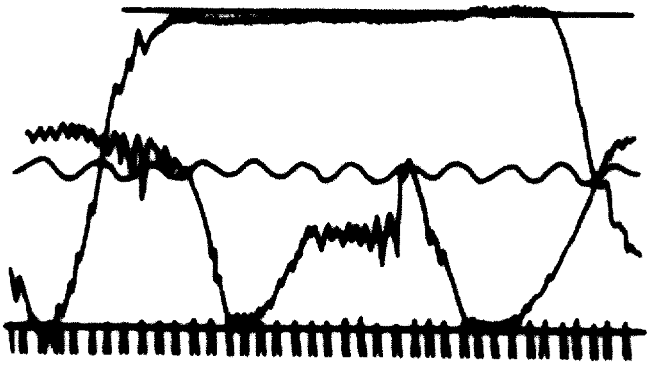

Figure 7. Oscillogram of the tensions of the needle thread and bobbin thread in a double-thread chain-stitch sewing machine

For technicians, the character of the changes in the dynamic tensions as functions of the speed of a given machine is specially important. The characteristics observed with some types of machines are illustrated in figure 8.[4]

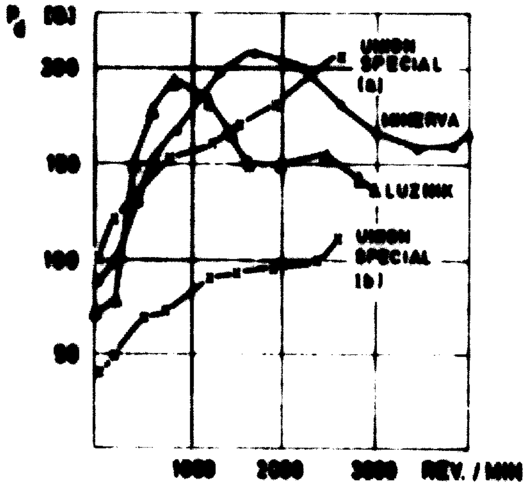

Figure 8. Change of dynamic tension (P_d) expressed in gram force (G) as a function of machine speed: (a) tension on the needle thread, (b) tension on the bobbin thread

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[4] The needle thread is subjected to three stretching impulses: the first during the drawing of the former loop (at the 25° peak), the second at the moment when the needle pierces the fabric (at the 90° peak) and the third when the bobbin thread enters the loop of the needle (at the 225° peak).

Tests have revealed that this characteristic differs from the others in that, to a great degree, it depends upon the construction of the machine. Figure 8 shows the changes in dynamic tension found with two lock-stitch sewing machines, namely the Lucznik LZ 3 (Poland) and the Minerva 321 (Czechoslovakia), and with the Union Special BP 51400 (United States), a double-thread chain-stitch machine. The fundamental difference lies in the fact that the maximal magnitude of dynamic tensions with the lock-stitch sewing machines is associated with relatively low speeds. This does not occur with the double-thread chain-stitch machines. When comparing the dynamic tension on the thread in various machines, it must be pointed out that there are distinct differences in its magnitude; the differences are twice as great at speed ranges up to 3,000 needle thrusts per minute. Furthermore, to obtain a double-thread chain-stitch, far less static tension on the thread is required. It is evident that this tension is smaller for the bobbin thread than for the needle thread.

The stitch-forming process requires a zone of stitch formation in a given machine. The dimensions of this zone are determined by the construction parameters of the machine. It is in this zone that the most intensive wear and tear on the sewing thread occurs.

Within the stitch-forming zone a separate section can be distinguished in which the thread is subjected to the actions of the instruments that form the stitch and of the fabric that is being stitched. The instruments and the fabric act, within a single cycle of the machine work, upon one definite section of a thread, and this section may be designated as the working zone of the thread.

It is evident that the smaller the zone of stitch formation and the shorter the time during which a thread passes through it, measured by the number of working cycles of the machine, the smaller is the wear of the threads. It can be assumed that the influence of the tools and the fabric stitched in the work zone of the threads does not alter. A given section of thread enters the stitch-forming zone and passes through a set number of cycles there. It has been found that the magnitude of the stitch-forming zone of the lock-stitch sewing machine is several times greater than that of the chain-stitch sewing machine. For this reason, the time of passage of a section of thread through this zone is much shorter. In addition, the actions of the working parts of the machine (that is, the actions of the bobbin catcher and the take-up lever) are not as powerful as in the lock-stitching machine. Changes of the

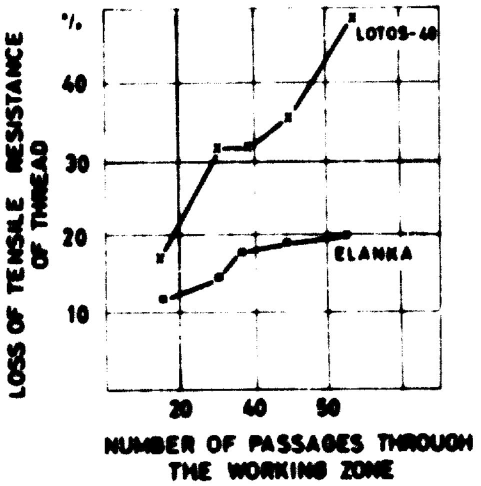


Figure 9. Drop of resistance (per cent) of two threads (Lotos-40 and Elana) after passage through a lock-stitch sewing machine

mechanical properties of the thread after it has passed through the stitch-forming zone may be quite important. For example, the losses of tensile strength of thread are considerable; under unfavourable conditions they may reach a magnitude of approximately 50 per cent (figure 9). At the same time, increase of thread diameter and its elongation occur.

It may be pointed out that the character of the action of the stitch-forming zone on the thread may change with alterations in the conditions of treatment. First of all, the thickness of materials sewn and the set (density) of the stitch depend upon the duration of the time of passage through the working (stitch-forming) zone. As has been noted, the dimensions of the stitch-forming zone are many times greater in lock-stitch sewing machines than in double-thread chain-stitch sewing machines and the required number of passages is appreciably smaller. In consequence, the time of passage of the needle threads through the working zone of the lock-stitch sewing machine is several-score times longer than with other machines. Thus, the thinner the cloth and the denser the stitch, the more the thread of the needle is subjected to wear and tear. However, the action of some technical parameters may operate in other directions. For instance, by increasing the thickness of the cloth pierced by the needle, the time of passage of threads through the working zone may be reduced (the per-stitch demand for thread would be greater) but, on the other hand, there would be a decrease in the resistance of the threads, caused by increased friction in the sewn cloth. Experimental evidence permits the statement that, for instance, by increasing the number of layers of cotton cloth sewn together from two to ten, the required tensile strength of the sewn thread may be halved, if a constant number of passages of threads through the working zone and a constant dynamic tension on them are assumed.

As noted above, extreme wear of thread in sewing machines may cause it to break. Unfortunately, there has been a lack of research and publication concerning this important subject. The problem of thread breakage is of special relevance in the design and construction of certain new types of machinery such as multi-operational and multi-needle machines as well as of automated aggregates in which the breaking of a single thread may cause the stoppage of a number of machines or even of the entire set.

Distinction should be made between technical breakage, which is caused by the mechanical conditions of the sewing process, and nontechnical breakage, which results from the faulty setting-up of the working components of the machine. Thus, in analysing thread breakage, it is important to determine its nature. Breakages of the first kind are often caused by weak spots in the thread, whether originally present or resulting from excessive wear during the sewing operation. In such a case, it may be possible to solve the problem by using thread of a better quality; if breakage is of the nontechnical kind, its cause must be found and corrected.

Because of their accidental character, the incidence of technical breakages should conform to the general laws of the random distribution; that is, with a defined distribution of breaks in the mathematical calculus of probability. It would seem appropriate to attempt to appraise the character of the occurrence within a definite time of breakage. Such an effort would be complicated by the fact that sewing machines do not operate at a constant number of revolutions per unit of time. For this reason, breakage as a function of the length of the seam at a constant stitch density was studied. Records were made in the manner shown in figure 10. On the axis that represents the length of a seam, the positions of the breaks were noted (sections $L_1, L_2 \ldots L_i$), further assuming a periodical division of the axis (section A_i) of the number of breaks falling within a given section. After calculating the number of sections with equal numbers of breaks, the distribution of the breaks was found. Figure 11 illustrates the empirical distributions of sections containing 0, 1, 2 or 3 breaks within lengths of 1, 2, 3 and 10 metres. A check of the empirical distribution permitted the statement that they are consistent with the theoretical distribution of possibility of the seldom-occurring phenomena; that is, with the so-called Poisson's distribution.

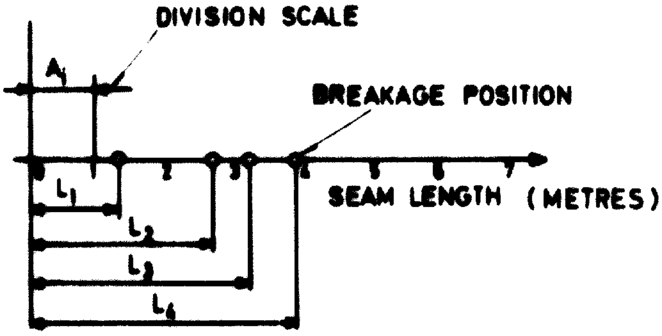


Figure 10. Scheme of thread-breakage analysis (see text)

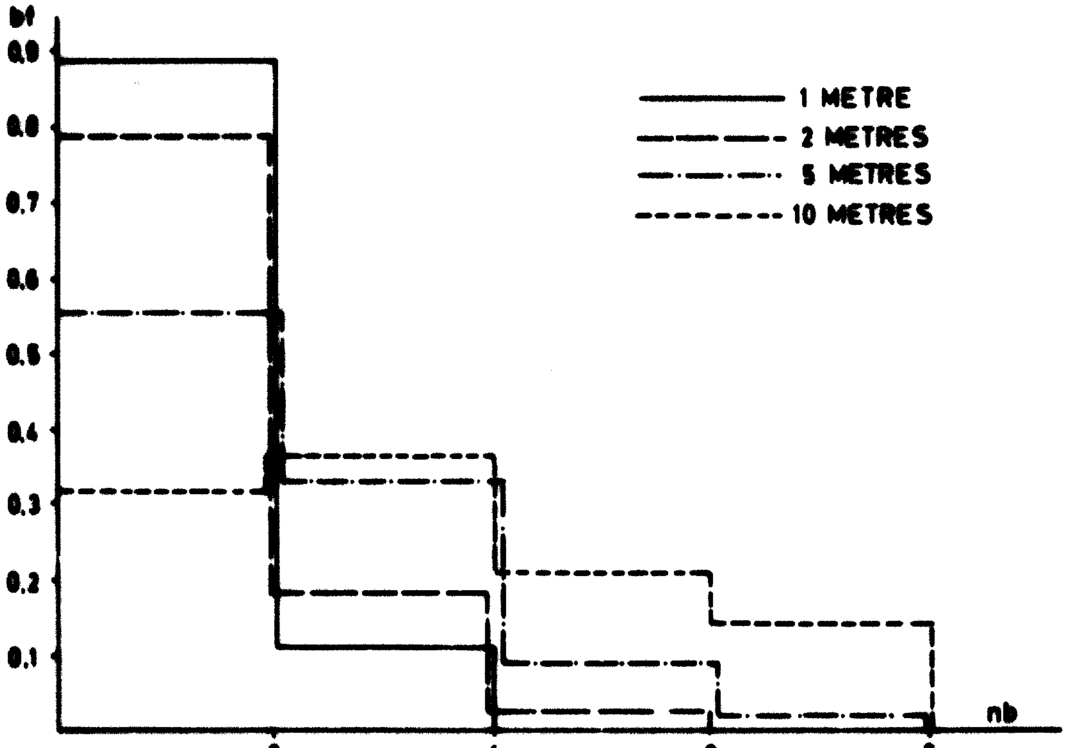


Figure 11. Empirical distribution of thread breakage at the seam sections: (bf) breakage frequency (number of sections with seam breaks), (nb) number of breaks per section

Appraisal of the character of breakage in this way makes it possible to ascertain whether a given empirical distribution of the thread breakage observed on a sewing machine is in accordance with the theoretical distribution. However, this requires the application of entirely new criteria of verification of the empirical distributions (for instance, a χ^2 distribution) and a definition of the probability of acceptance or disapproval of the zero hypothesis. Also, Poisson's distribution does not account for some cases. In these, a more complicated mathematical method must be used.

Observations recorded at the Clothing Institute of the Łódź Polytechnic School permit the statement that the rate of incidence of technical breakages changes fundamentally, not only under identical conditions of machine work (a diversified technological regime) when different threads are used, but also when the same threads are used under different working conditions.

Figure 12 illustrates changes in the breakage of thread as a function of the number of working cycles in the stitch-forming zone of a sewing machine using the Polish cotton threads Lotos–70 and Zubr–50 under identical conditions of machine work. The breakage observed was of the technical type.

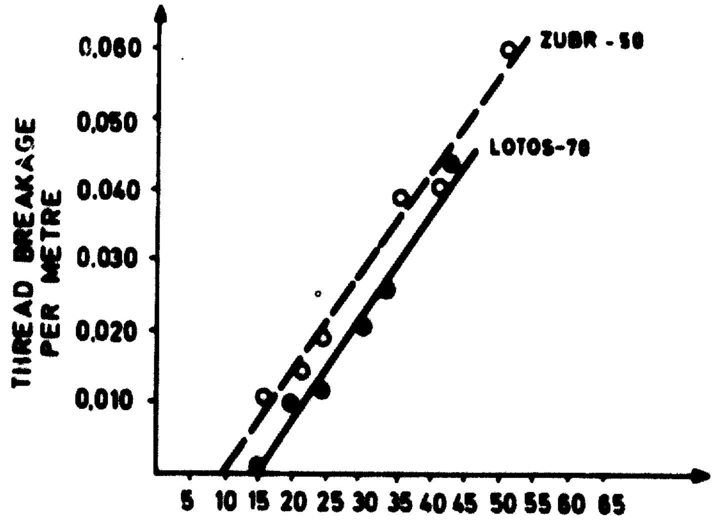


Figure 12. Relation of thread breakage to the conditions of forming a stitch (number of passages of the thread through the working zone of the machine)

The results of a series of such tests permit the statement that the possibilities for automation of clothing manufacture on the basis of sewing are rather limited. These limitations derive from the principles of formation of thread fastenings and are connected with the phenomenon of destruction of thread during the sewing process, as well as with the occurrence, in extreme cases, of thread breakage. Comparison between the lock- and chain-stitches leads to the conclusion that the technical reasons are decisive as to the greater adaptability of chain-stitches to the automation of manufacture of clothing by sewing techniques. It must be made clear that, whatever kinds of stitches are used, the automats that form the thread fastenings are characterized by high price, which largely reflects the high cost of the transporting mechanisms. As was pointed out earlier in this article, the production of clothing with the aid of the thread seams must be classed as an operation of a low grade (that is, of the first class), and the transporting mechanism must execute transport along the three axes *X*, *Y* and *Z*. This requirement necessitates high constructional complexity, with consequent high cost. It therefore seems suitable to introduce into clothing technology methods of higher grades; that is of the second and third classes, and verification of these methods under existing conditions in industrial production and, finally, the automation of the processes on the basis of these new methods. New possibilities are being created by the development of adhesive bonding methods, which have found application to the manufacture of clothing in recent years.

Techniques for adhesive bonding

The use of bonding agents in clothing production is a concept as old as the use of threads for joining, but it could not be applied until recently because of the lack of suitable bonding materials. Natural glues are unsuitable, since they lack satisfactory chemical and physical properties. This problem is being solved by the development of synthetic glues and other bonding agents.

Synthetic glues were originally introduced in the Soviet Union in 1948 and became widely used all over the world. In some countries, among them Czechoslovakia, East Germany, the Federal Republic of Germany, Hungary and the United Kingdom, a wide range of bonding agents is in use as basic and auxiliary products. These adhesives are supplied in forms of pastes, foils, powders and inserted pads composed of woven or non-woven fabrics covered with a layer of adhesive. The conventional way of producing an adhesive bond by means of a thermoplastic insert includes heating the bonding element, transforming it into a fluid state under the action of high temperature and securing the proper contact by squeezing the components together in a press. A conventional type of press, such as an ordinary clothing press, is normally used. The application of adhesive bonds in this way does not require any important outlays of capital, and the problem is merely that of supplying the industry with a wide range of adhesive inserts.

A slightly more complex problem is presented by the application of bonding agents in form of foils and powders, as additional equipment for decomposing bonding agents and proper application of powders is required.

The choice of adhesives for joining materials in clothing production is determined by the requirement that the quality of a bonded seam must not be inferior to that of a thread seam.

These demands may be summarized as follows:

(a) There must be a sufficient resistance of the bonded seam to both static and dynamic loads; the strength of a seam depends primarily upon the adhesion between the fabric and the bonding material.

(b) The stiffness of a bonded seam should not be great; it should not differ in this respect from a thread seam.

(c) The adhesive must be resistant to the action of water and of the solvents commonly used for removing stains and for cleaning garments.

(d) The bonding agent must have good mechanical qualities within the range of temperatures required by nature of the clothing.

(e) The adhesives must be resistant to ageing under the influence of the atmosphere (rain, sun, changes in temperatures and the like) within the period of use foreseen for the garments.

All of these requirements are related to the kind of joint (permanent or temporary) and to the conditions under which the clothing will be worn.

It must be pointed out that the typical thermoplastic bonding agents do not fulfil all of these requirements. This is especially true of demand (*d*) above. Adhesives of this kind tend to liquefy, sometimes within the range of temperature in which the clothing will be used. Such melting, although originally small, tends to rise over the period of use of the clothing. Consequently, the purely thermoplastic bonding agents cannot be used to form durable primary joinings.

Mixtures of thermoplastic and thermoreactive resins are used for netting of this kind. Heating such blends often causes netting of the thermoplastic polymer. An example of such a blended bonding agent is the OP 1 adhesive used in the Polish garment industry. The active ingredient of this material is a mixture of a modified polyamide and FF (phenol formaldehyde) resin.

Within the last decade, other variations of the principle of adhesive joining of fabrics have been used in the clothing industry. These are the heat-sealing and welding linkages, which are based on the same physical and chemical phenomena as in the bonding methods described above. Since they are still in the experimental

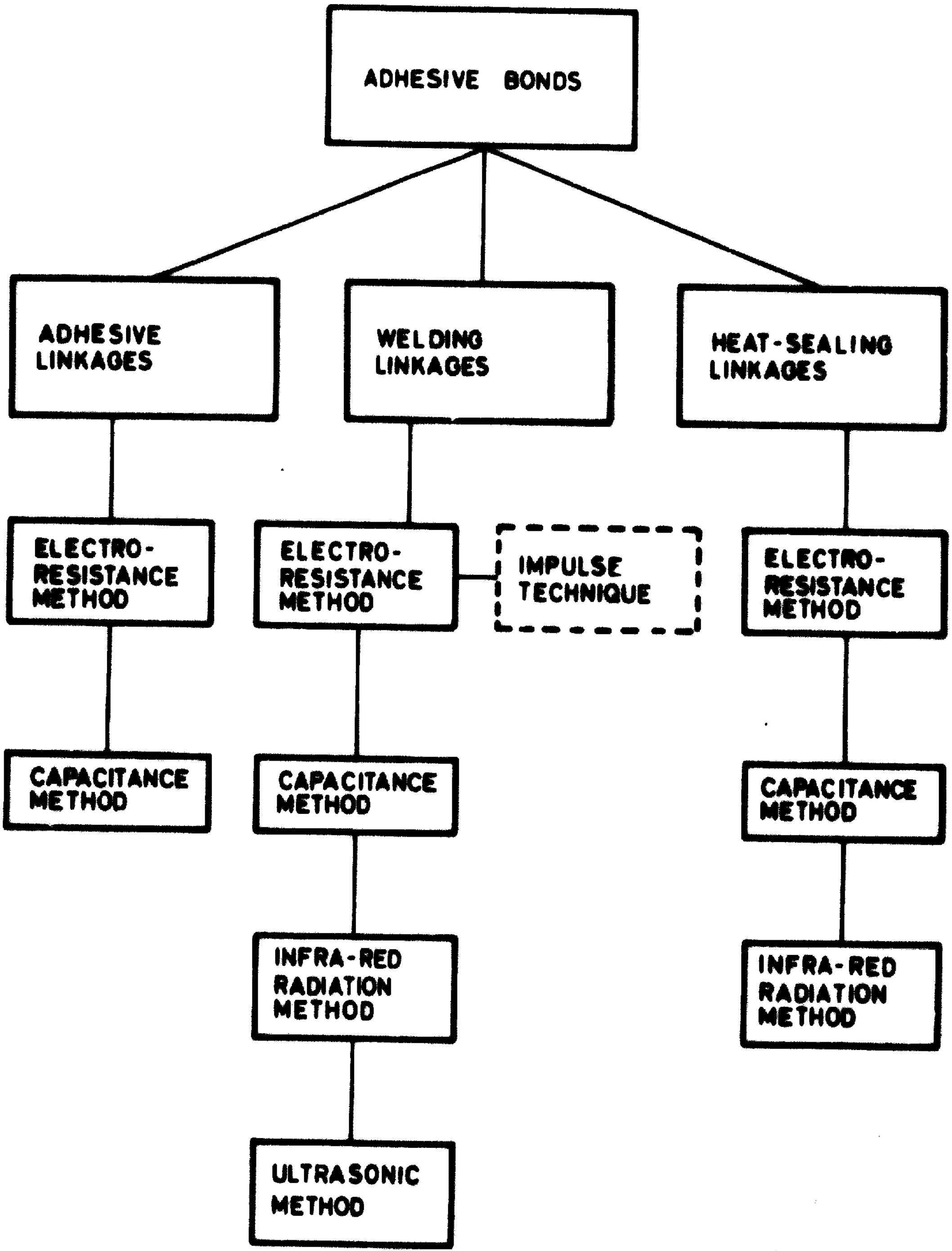


Figure 13. Classification of adhesive linkages

stage, the course of their future development cannot be foreseen. Meanwhile, however, their suitability for the processing of some clothing elements made from synthetic materials must be stressed.

There can be no doubt that some problems are caused by damage to the heat-bonded fabric and to difficulties in the mastery of welding techniques that use ultrasound or electrical currents of very high frequency. However, it is reasonable to think that techniques for forming heat-sealed and welded fabric linkages will be developed further.

From the technological standpoint, distinction should be made among the many possible ways of forming these fabric linkages, according to the ways in which heat is applied and the linkage made. Because of the great number and variety of these methods, it is advisable to classify them in an orderly manner. A system for dividing them into three groups, according to whether they are formed with the use of adhesive materials or by welding or heat-sealing is presented in figure 13.

In linkages made with adhesives, the fabrics are joined by the application of a special adhesive substance that melts when heated. It is also possible to use bonding agents in solution, but this method is noneconomic in the clothing industry.

Linkage by welding is done by means of the partial transformation of a bonded fabric to a plastic consistency without the use of an additional bonding material. This method of joining naturally requires thermoplastic properties in one of the joined materials.

Heat-sealing linkage requires the transformation of both the bonding agent and the fabric into a plastic or liquid state in which the separateness of these two elements disappears.

It follows from the above-mentioned classification that any given type of adhesive bond may be obtained with the aid of different types of machines and devices, and in some cases the same types of apparatus and of machine may be used to produce linkages of various types, according to the conditions of treatment. It is therefore necessary to analyse the fundamental method of forming of linkage and to define its scope and suitability for automation of the processes of clothing production.

It is evident that the simplest way to obtain an adhesive bond is by linkage with thermoplastic adhesives that have been melted by resistance heating, with simultaneous compression of the seam. Figure 14 illustrates a typical scheme of obtaining a linkage by means of thermoplastic adhesive. Between the layers of the textiles (or other materials) linked, a layer of adhesive material is deposited that must be melted by the application of heat. Assuming that the pressure (p) and temperature of the heating plate are constant, the temperature required to melt the adhesive may be expressed as:

$$\Delta t_T = T - t_T \qquad (1)$$

where:

T is the temperature of the heating plate (panel)

Δt_T is the decrease of temperature within the time τ caused by the insulating power of a layer of the materials situated between the heating plate and a layer of adhesive

t_T is the temperature of the adhesive during the time τ, calculated from the moment of closing the press.

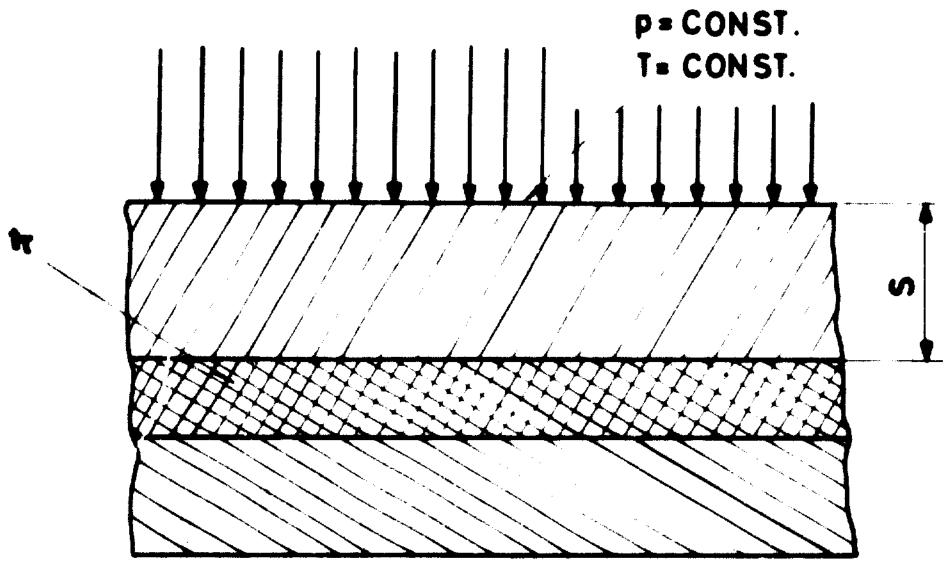


Figure 14. Diagram of the formation of a fabric linkage with the use of a thermoplastic adhesive (see text)

It is readily seen that the decrease of the temperature Δt_τ is a function of the insulating power of the heated layer (S), its thickness and the duration of the time of pressing.

If the initial temperature is t_0, the temperature at which the bonding agent melts is t_k, and T is the temperature of the heating plate limited by the insulating power of the cloth, the maximum permissible temperature drop (Δt_{max}) may be calculated as follows:

$$\Delta t_{max} = T - t_k \tag{2}$$

Both equations (1) and (2) may serve as bases for the regulation of the parameters of fabric bonding with the use of thermoplastic materials. A nomogram for the calculation of the parameters of adhesive bonding processes is illustrated in figure 15. The basis for the calculations is modification Δt_τ, which depends on the thickness of the bonded layer of materials (magnitude S). For the execution of the nomogram, the function of Kramp was utilized, as the basis for changes of the temperature within the period of time τ (seconds). When analysing the set of parameters presented in the nomogram, the scope of application of the contact (resistance or steam) methods of heating a seam may be defined. It must be assumed, from what ensues from the character of the run of the curves $\tau =$ constant, that the application of heat for periods of time longer than 90 seconds is not reasonable:

$$\tau \leqslant 90 \text{ sec} \tag{3}$$

The limitation illustrated by means of inequality (3) defines simultaneously the scope of the described method of fabric linkage. When using one of the systems for making heated linkages that have been described, in which a partial destruction of the heated materials is possible, the foregoing reasoning is not applicable. Furthermore, in similar cases it is possible to apply temperatures of the resistant heaters ($T \neq$ constant) that exceed the limits of the thermal resistance of the heated materials. This method is called the "impulse technique".

Another method of heating seams of great thickness is that of capacitance heating by a high-frequency field. This method may be applied with success to clothing technology, provided that the adhesive (or, in case of welding, a linked

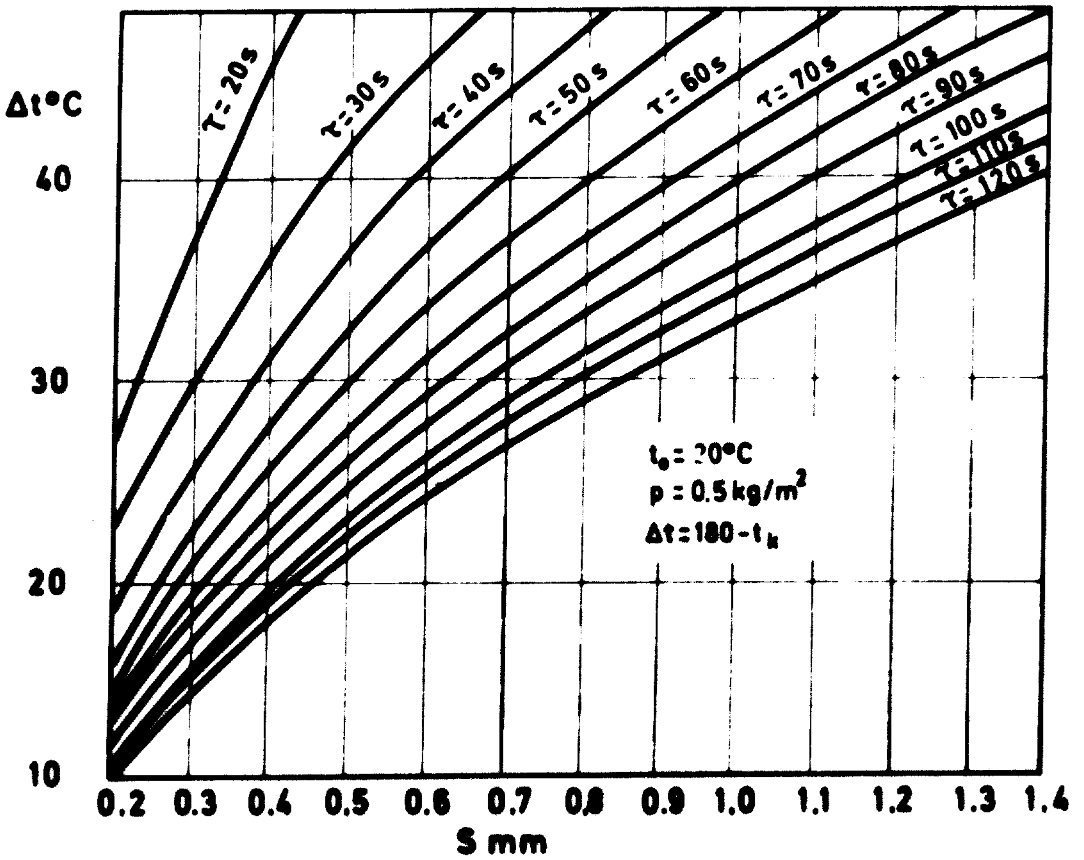


Figure 15. Nomogram for calculating the parameters of fabric linkage by contact heating of adhesive seams (see text)

material) possesses suitable dielectric properties. Losses of energy in the heated insulator within a high-frequency field conform to the equation

$$N = 0.555 \times fF^2 \epsilon \operatorname{tg} \theta \times 10^{-12} \qquad (4)$$

where:

N is the voltage loss in volts per cubic centimetre (V/cm³),
f is the frequency in hertz (Hz),
F is the intensity of the electrical field in V/cm,
ϵ is the dielectric constant, and
tg θ is the tangent of loss angle.

Capacitance heating methods are very popular throughout the world and are commonly used for heating materials, and they may also be used to form fabric linkages. In this case the work of the heating devices is less complicated and does not require regulation of bonding parameters, since the properties of the adhesive material are constant. During heating, the parameters must, in each case, match the magnitude ϵ tg θ of the bonded material.

The industrial application of capacitance heating is associated with a number of difficulties, among them the need to provide safeguards against electromagnetic interference. The one most commonly used is the so-called "Faraday's cage", which suppresses them completely. From the technical standpoint, production problems are of primary importance. The basic one, which constitutes a limitation, consists in the too-small value ϵ tg θ of some bonding materials such as polystyrene and polyacrylonitrile. While it is theoretically possible to increase dielectric losses by adjusting the frequency or intensity of the field, there is an associated risk of sparking and damage to the fabrics that are being joined. However, there are means of diminishing these losses, such as by coating the fabrics to be joined with a substance that has a great ϵ tg θ value or by the use of suitable adhesives. It is probable that this method will be widely applied in the clothing industry, as it may be exploited for the simultaneous processing of all the elements of clothing. Treatment of the entire contour or surface of clothing by the capacitance method permits raising the range of the technical process so that it may be included within the operations of the second and third classes. It is evident that the construction of an automat that operates on this principle would make possible an economically effective application of automation to clothing production.

In the ultrasonic method of heating, it is essential to introduoe the oscillation energy into the heating zone. The fabrics to be joined are laid on a base called an "anvil" and pressed down by a predetermined force to a vibrator that oscillates with a frequency in the range 18 to 22 kHz at a right angle to the surface of the heated elements.

A heat sealer usually consists of the following parts:

(a) A high-frequency (HF) device that converts electrical oscillations into mechanical oscillations;

(b) A speed transformer, also called a "concentrator of energy";

(c) A pound element, called a "sonotrode";

(d) An anvil;

(e) A pressing device.

Magnetostrictional oscillation converters are commonly used in the technology of clothing. These converters are constructed of ferromagnetic material, and their dimensions change under the influence of the lines of force of a magnetic field (the phenomenon of magnetostriction). A typical layout of an ultrasonic welding device is presented in figure 16.

The range of application of ultrasound heating in clothing technology is still restricted by the limited possibilities of linear heating in this way. The emission of a beam wider than 120 mm is not yet possible technically, and for this reason ultrasonic heat-sealing can be applied only to a limited number of operations. Instances of the use of this technique for making buttonholes and the like may be cited.

Ultrasonic welders may be used for continuous heat-sealing, passing the fabrics to be joined in a continuous manner, or by jumps (strokes) between the sonotrode and the anvil. In the latter case, the sonotrode has a flat, curved form such as a disk; this arrangement copies exactly the action of a sewing machine. An example of such a device is the SL 21 MK II, a construction designed by the Omega Laboratory (United Kingdom). This device may be used to weld woven or light knitted fabrics. This apparatus is supplied with a controller of 600 volts working on a controlled frequency of approximately 30 kHz, and can heat-seal fabrics at a speed of approximately 10 m/min.

A device that operates on this principle is clearly one that performs a technical operation of the first class. A device of this type has an adaptability to automation similar to that of a conventional sewing machine. It may therefore be expected that, for some materials that suffer frequent damage during the sewing process, the application of ultrasonic welding may prove to be advantageous, but the economic efficiency of automation with this process is questionable.

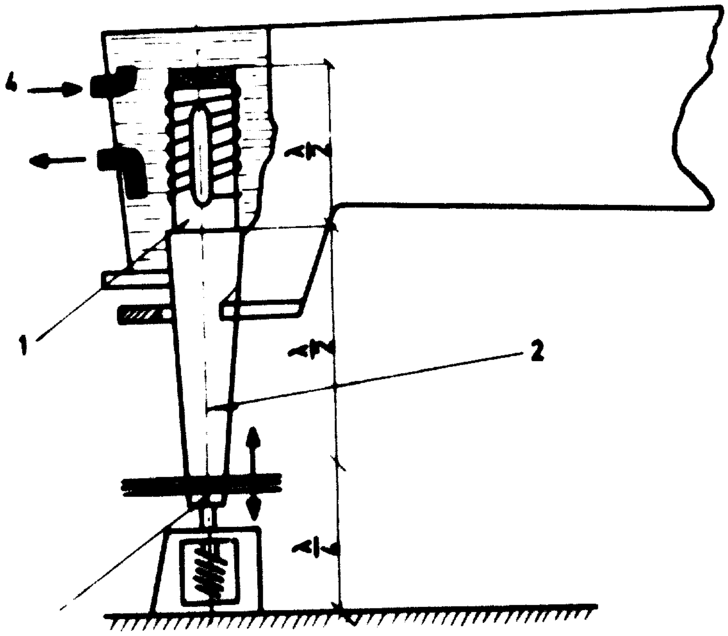


Figure 16. Schematic drawing of an ultrasonic welding device: (1) magnetostrictional converter, (2) transformer, (3) anvil, (4) cooling of the transformer, $\frac{\lambda}{4}, \frac{\lambda}{2}, \frac{\lambda}{2}$ *acoustic wavelengths*

To sum up this appraisal of adaptability of various methods of processing clothing for the automation of the making-up process, the five following statements may be made:

(a) Further development of sewing machines, directed toward the replacement of lock-stitch processes by double-thread chain-stitching must be expected. The automation of these machines should evolve in the direction of the formation of multifunctional systems and of ranging various machines in parallel.

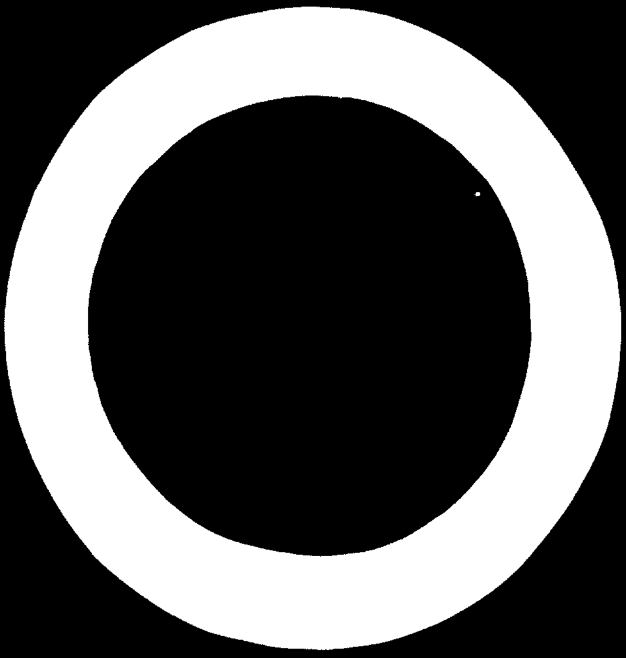
(b) Serious obstacles to the automation of making-up processes for clothing are their low economic efficiency and their complex manner of operation (processes of the first class).

(c) A serious possibility for modernizing the making-up processes, of forming the basis for a new technique and of its simultaneous automation lies in introduction of adhesive linkages (operations of the second and third classes).

(d) Among all the methods of forming adhesive linkages, the best and most efficient appear to be the methods of bonding with adhesives and of contact welding with the aid of resistance heaters or with capacitance heating methods.

(e) At the present stage of their development, the application of the ultrasonic welding methods to clothing production has a limited scope and cannot form a solid basis for planning the automation of the production of garments.

It also appears that there is a need for research on the efficiency of the automation of garment manufacture, taking into consideration the new techniques as well as a thorough exploitation of the older methods of production. It is essential to create new possibilities for the combination of various methods of treatment with the aid of thread and adhesive linkages, directed toward the automation of the production of clothing.



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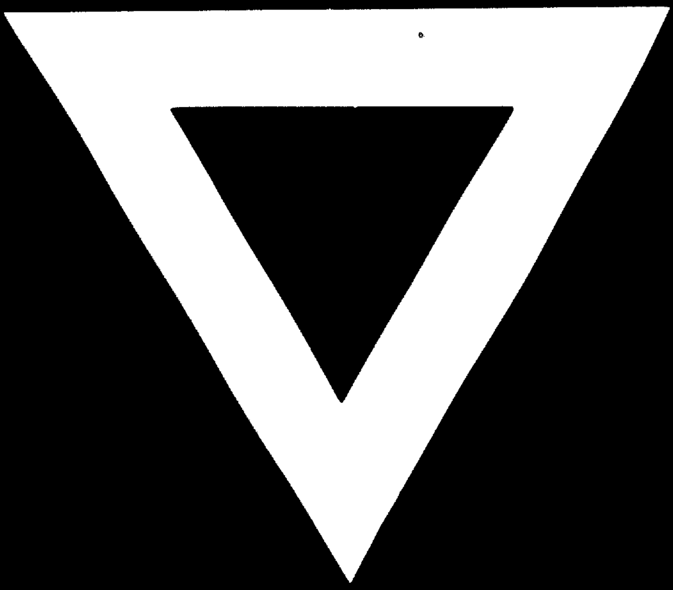

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