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Karlovy Vary, CSSR, 24 February - 14 March 1969

APPLICATION OF THE PRESSURE DIE-CASTING PROCESS TO THE PRODUCTION OF LIGHT METAL CASTINGS IN THE AUTOMOTIVE INDUSTRY.

by

J. Valecký

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APPLICATION OF THE PRESSURE DIE-CASTING PROCESS TO THE PRODUCTION OF LIGHT METAL CASTINGS IN THE AUTOMOTIVE INDUSTRY[1/]

by

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* This is a summary of a paper issued under the same title as ID/WG.13/15.

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Application of the Pressure Die-Casting Process to the Production of Light Metal Castings in the Automotive Industry

This paper deals with the following problems:

Series or mass production of motor vehicles, especially of automobiles, depends, inter alia, upon the application of progressive production methods to the production of metallurgical semiproducts.

The semiproducts of Al, Mg or Zn alloys used in the manufacture of automobiles, may be divided, as far as the casting procedure is concerned, into the following three groups:

a. Semiproducts for chassis component parts;
b. Semiproducts for body component parts;
c. Semiproducts for accessories.

The semiproducts of the first group are produced mainly of Al or Mg alloys.

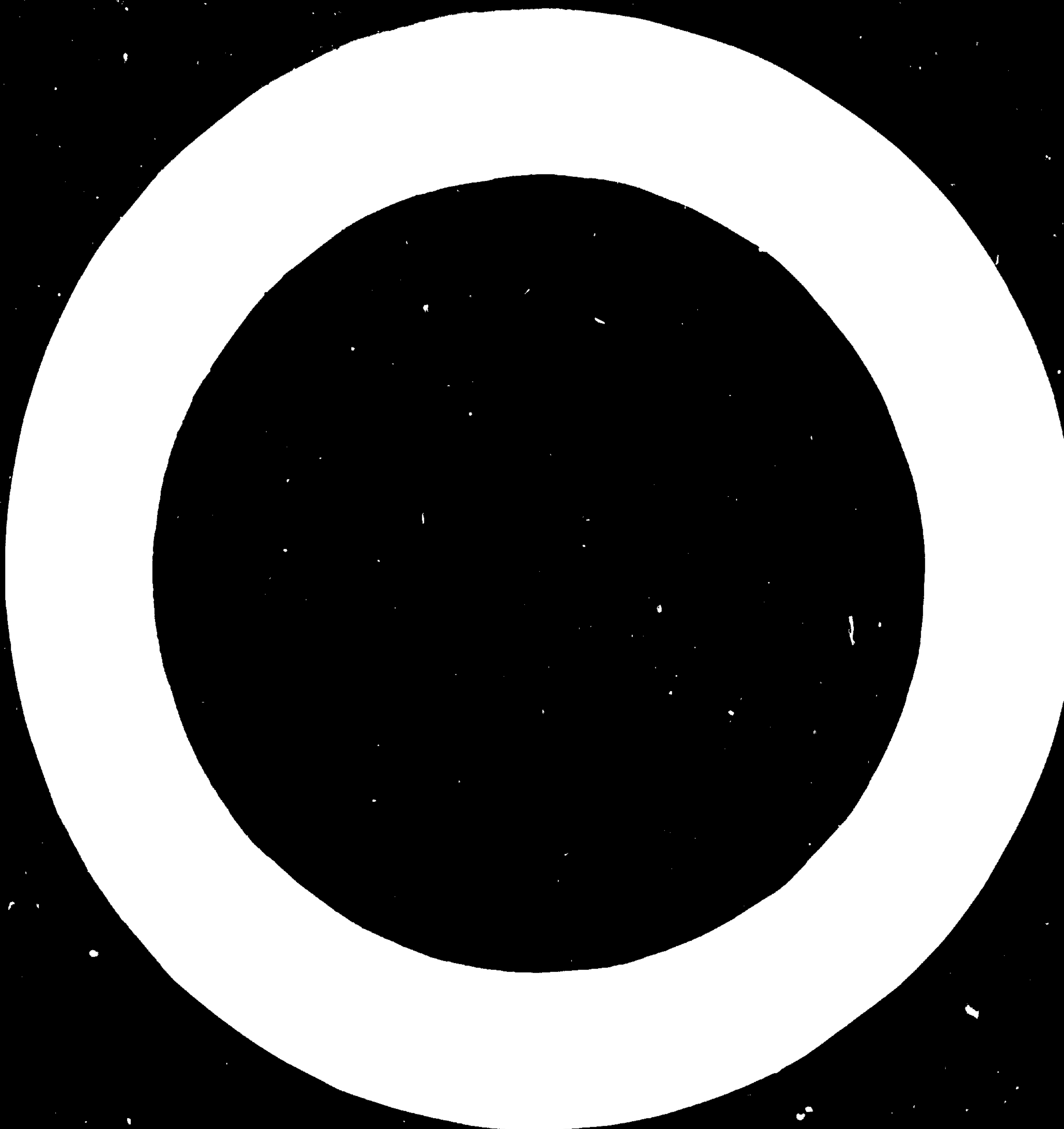
Demands on these castings include:

a. Adequate mechanical values, as to tensile strength, hardness, ductility;
b. Dynamic load properties;
c. Impermeability of walls;
d. Sufficient heat strenght;
e. Dimensional stability;
f. Excellent machineability.

The effort to gain a position as supplier of castings for chassis component parts has forced the producer of castings to search for new production methods and to compare their technical, technological and economical advantages. In the last decade the United States has attained the necessary technological level in the production of pressure die-castings of Al-alloys. At the same time the production of pressure die-castings has been widely introduced in Czechoslovakia and applied to single-track vehicles.

Our development in this field, carried out mostly in the Automobil Works at Mladá Boleslav led to the determination of some important interrelationships, viz:

a. The influence of pressure applied to the melted alloy when filling the die upon the tensile strength of the alloy;
b. The influence of the flow velocity of the melted alloy upon tensile strength;



c. The influence of the chemical composition of the alloy upon ductility and tensile strength;
d. Determination and specification of the influence of technological conditions of casting upon dynamic strength;
e. Determination of the necessary casting conditions to obtain impermeable casting walls,
f. Elaboration of procedures ensuring the dimensional stability of castings;
g. Elaboration of procedures to obtain excellent machineability.

The semiproducts for body component parts have the character of artificial jewellery. The subjects under discussion are fittings, radiator grilles and other groups of trimming /decorative/ parts. These were already produced in the past by the pressure die casting process from Zn-alloys. After casting the finished parts were electroplated.

The above procedure is broadly used by West German and American producers. It has been further improved by casting into vacuum dies. In this way castings with perfect homogenous surfaces, and hence also with perfectly homogenous electroplated coatings, were obtained.

For these products, the Al-Mg alloy AlMg-9 is used in this country. It is stable and possesses good polishing properties.

The semiproducts for accessories comprise, in the first place, castings for carburators and fuel pumps. They are mostly produced from Zn alloys possessing high dimensional stability, with all holes cast. The remaining castings for accessories /generators, starter motors, windshield wipers/ are, in the majority, made of Al alloys. The application of pressure die castings has the following advantages:

a. High dimensional accuracy with low deviations of individual castings facilitates the design and application of clamping devices;
b. Small and uniform machining allowances together with accurate clamping reduce the amount of chips during machining;
c. Small and uniform machining allowances make it possible to introduce more progressive machining methods, such as internal and external broaching;
d. The cadence of production is much higher than with other metallurgical methods; therefore by the pressure die casting method castings even for a very high production scale of the motor vehicles can be produced;
e. The pressure die casting method allows for casting of much thinner walls than do other procedures. Thanks to this dimensional accuracy no allowances for production deviations need be involved in the design and size determination of the parts to be cast. The material demands by the pressure die-casting process are 15% to 30% lower than by conventional casting methods; qualified founders can

easily be /replaced/ by trained workers.

However the pressure die-casting process has the following disadvantages:

a. Thus far only metals with melting temperatures up to 1000°C can be used. Pressure die casting of steel and cast iron is only under development;
b. The tools /dies/ to be used are rather intricate;
c. The preparation of the pressure die-casting process imposes higher demands upon the skill of the engineering staff.

In addition to the material savings the pressure die-casting process reduces other production costs. On the average, the cost per piece can be lowered by as much as 15% to 30%.

When projecting new automobile plants or rebuilding existing ones, economic analysis and comparizon of various methods should be carried out first to determine which of them would be the most suitable for production of the given type of casting.

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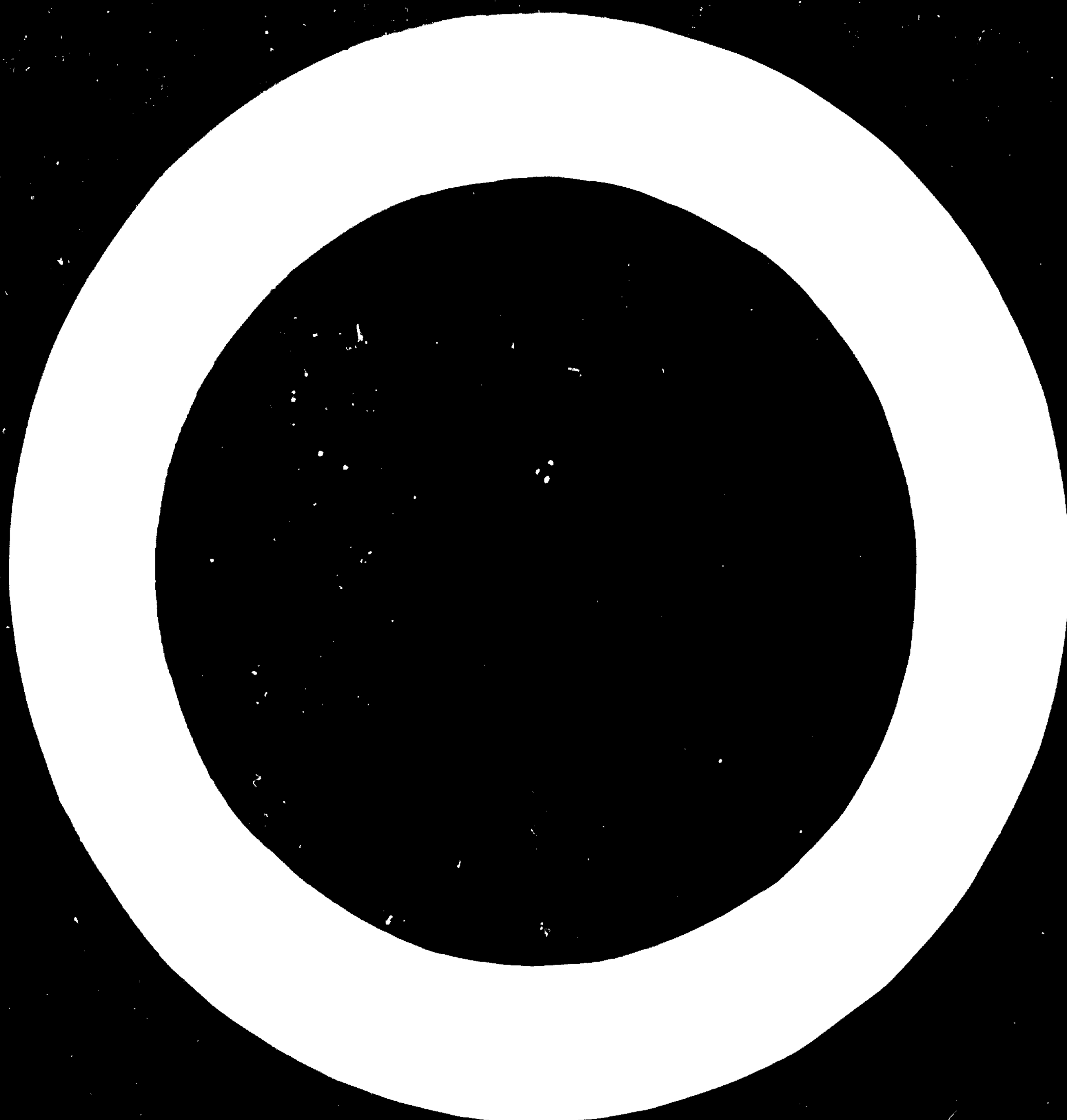

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The Application of Light Metal Castings, Produced by the Die Casting Process, for the Construction of Motor Vehicles.

Introduction

When comparing the technical and economic aspects of technological processes, by which parts of motor vehicles are to be produced, the die casting process is often found to be advantageous. It is almost always advantageous, if it is to be used for the production of a part, which has been hitherto produced by welding of a number of stampings. E.g., the bottom reflector guard of the well-known motorcycle Jawa, which was originally produced by welding four cold formed stampings, is now being produced by the die casting process /Fig. 1/. By applying this technology of die casting, the production costs have been reduced by 14 %. Another example is the part of the bottom casing of the motor Škoda 1000 MB, which is being produced either by stamping /Fig. 2/ or by die casting, the casting being provided with both inner and outer cooling ribs /Fig. 3/. In this case, no production costs savings have been achieved by the adoption of the die casting process, but the heat passage from the oil bath of the motor to the surrounding atmosphere has been substantially increased.

I. Classification of the Process

The process of die casting is defined as a method of casting, according to which the mould cavity is filled under a pressure exceeding the gravitational pressure of the column of the liquid alloy of a common height. According to the value of the pressure, under which the mould cavity is being filled, the die casting process is classified as follows :

- low-pressure casting, when the filling is carried on under a pressure of about 0,2 atm.

- pressure-casting, when the filling of the cavity is carried out under a pressure higher than 50 atm., commonly in the range of 300 atm up to 3000 atm.

II. The Development of the Quality of Castings Produced by the Die Casting Process

The opinion that castings, produced by die casting, are of a lower quality in comparison to castings, produced by classic methods, as e.g. sand casting or chill casting, originates in the past. When the die casting process is being applied, the quality of castings can get substantially worse if the technology of casting is not fully controlled or if the technological regime is not respected during the casting operation. It was the aim of foundries to get contracts for supplies of castings for the construction of motor vehicles, which first led in 1949 to 1954 to an intensive development of the pressure casting process with the goal of a substantial enhancement of the quality of castings. This development has been carried out mainly in the USA - the Dehler Jarwis Toledo Company - as far as concerns castings for motorcars, in the Czechoslovak Republic the national enterprise České závody motocyklové /Czech Motorcycle Works/ in Strakonice, later on in the national enterprise Automobilové závody /Motorcar Works/ in Mladá Boleslav. The result of the aforementioned works, which were gradually published in special journals, is an enhancement of the inner quality of castings produced by the die casting method to the quality level of castings produced by classical casting processes. By the enhancement of quality, the scope of application has been widened. The diagramm in Fig. 4 shows the rate of production of castings, produced by the die casting process in general. The increase in the volume of production is for the greatest part due to the increase of production of castings for motor vehicles.

III. The Results of Research and Development Work

Works, which have been carried out in Czechoslovakia in the field of the research and development of the die casting process resulted in the definition of some important technological relations, which influence the quality of castings. Let us mention e.g. :

- the relation between the specific pressure of the alloy during the filling of the mould cavity and the tensile strength of the alloy. The relation for an aluminium alloy is shown in Fig. 5. From the figure it can be seen, that the tensile strength increases with an increasing specific pressure on the alloy up to the value of 1800 kp/cm^2. A further increase of pressure, which is both from the technical and economic points of view rather difficult, brings about only a slight increase of the tensile strength of the alloy. Therefore, modern die casting units for aluminium alloys, i.e. units with a cold horizontal chamber, are provided with a continuous control of the filling force and it is possible to work without difficulties with specific pressures up to 2000 kp/cm^2.
- the relation between the strength of the alloy and the flow velocity of the alloy in the gate during the filling of the mould. This relation is shown in Fig. 6. It can be seen from the diagramm, that the strength of the alloy increases parabolically up to the velocity of about 60 m/sec precisely 57 m/sec/. This finding is being applied when solving the problem of the location of the gate and of its dimensions.

- the optimum time of the mould cavity filling has been established, which assures that the casting does not include air and gas pockets, and that it has at the same [illegible] a high quality surface. When establishing the optimum time of the mould cavity filling, the well-known relation, defining the time of solidification of an unbounded plate of the following formula has been applied :

$$\tau = k \cdot \sqrt{\frac{s}{2}}$$

where τ =, solidification time

k = heat removal constant

s = wall thickness

Because the cavity has to be filled prior to the crystallisation of 20 % of the alloy volume it is a case of parabolical relation between the wall thickness and the time of filling of the mould cavity. The relation is shown in Fig.7 The optimum time of the cavity filling is a compromise between two extremes, i.e. between a slow filling, during which it is possible to let the gases escape from the cavity /to deaerate the mould/, but it is not possible to attain a faultless coherence of the flowing alloy. The other extreme, a very fast filling, results in agood coherence of the alloy flow, but, at the same time, a certain volume of gases is closed in the alloy flow. T[illegible]t of the optimum filling time serves during the construction of the mould for the calculation of the dimension of the gate and to the determination of the velocity of the filling piston of the machine during the casting operation.

- the optimum velocity of the alloy flow in the gate has been established. For the determination of this value, both the wall thickness of the casting and the maximum length of the alloy flow in the mould cavity have been taken into consideration. The relation between the optimum velocity and the values mentioned is shown in Fig. 8. The diagramm is being applied for the calculation of the gate dimensions.
- the maximum time interval, during which the effect of the increased filling pressure must be remarkable in the casting cavity, has been established. For the establishment, a measuring equipment has been used, similar to that used by the company WOTAN-VWF Düsseldorf. The maximum time-interval depends on the gate thickness lesser then 0,04 sec. A reproduction of the graphical record of the measuring equipment is shown in Fig. 9. Provided the optimum mould cavity filling time and the optimum alloy velocity in the gate are maintained, the accurately timed effect of additional pressure enables to attain quite homogeneous casting walls. The measuring equipment is shown in Fig. 10.
- one of the basic demands is a good machinability of the castings. It is characterized by a high quality of the machined surface and a long cutting life of the edges of cutting tools. Even if this condition was maintained, it was thought in the past, that castings, produced by die casting of aluminium alloys, were less machinable due to the higher content of oxidic films and non-metallic inclusions. By choosing appropriate systems of melting and holding furnaces, it is possible to attain a very good machinability even with castings produced by the die casting process. The presence of oxidic films in the melt can be reduced to a minimum by the use of

electrical induction channel furnaces, both melting and holding. The holding furnaces must be provided with an automatic feeding appratus. It is indispensable to enable a thorough refining either by appropriate salts or gases to be carried out. An example of appropriate melting furnaces is shown in Fig. 11, a holding furnace with a feeding appratus in Fig. 12, a refining chamber with good exhaustion for the refining of the melt is shown in Fig. 13.

- by means of water analogy /the viscosity of water at 20 °C is very near to the viscosity of the molten metal at 750 °C/ and the use of slow motion, the analyses of processes in the mould cavity during the filling and of processes in the filling chamber have been carried out, using transparent moulds. In Fig. 14, an enlarged shot of the filling of a multiple mould is shown. Fig. 15 represents the process in the filling chamber ofa die casting machine.

Other processes, which influence the quality of castings, have been analysed. The results make possible to find safe solutions of moulds especially of the filling, deaerating and ejecting systems. Further, they make possible the establishment of appropriate casting parameters, necessary for the attaining of dimensionally accurate castings of a good quality of material at low production costs.

The utilization of the aforementioned development work brought about such an enhancement of the quality of castings produced by the die casting process, that such castings were applicable even for the parts of chassis exposed to the greatest stress, as e.g. the cylinder block of water-cooled motors, the bodies of gear boxes, the bodies of steering boxes etc. In Fig. 16, some examples of castings, produced by the die casting process in great series, are shown, which are used for the construction of passenger cars and of motorcycles. Whereas cylinder blocks produced by die casting are used only by some manufacturers of cars /Škoda 1000 MB, Renault R-16, Peugeot 302, Lancia Flavia, Chevrolet, Hillman, Čajka and motor casings of all types of the Volkswagen-cars/, nearly all manufacturers use castings produced by die casting for gear boxes. Some examples of cylinder blocks, gear box halves and steering gear boxes are shown in Fig. 17.

The tightness of casting walls, resulting from the introduction of the findings of development work into praxis, mad it possible to utilize castings produced by the die casting process in a whole range of other parts, such as the front face of the crank case, the thermoregulator case, the main cylinder of the brake and clutch, the front lid of the gear box, the fan arm etc. Some examples of the mentioned castings are shown in Fig. 18.

Some castings can be produced only by die casting, as e.g. castings of valve gear bodies of the hydraulic control of some servofunctions in the vehicle. It is a casting with many flat channels and openings for the distributing valves. Very close dimensional tolerances are required in the case of flat channels, the vertical walls of which form the distributing edges of hydraulic distributing valves. The single channels must be entirely close one to another. It is very difficult to maintain these conditions by using other technological processes. An example of castings of this kind is shown in Fig. 19.

The good wuality of castings produced by the die casting process made it possible to pass over to this process when producing a range of aluminium-alloy castings, which were hitherto produced by sand casting or chill casting. It brought about, besides other advantages, a reduction in the alloy consumption per part, the reduction of labour costs per product and an increase of the production speed. The aforementioned advantages result, in the whole, in the reduction of production costs. So, e.g., for the set of castings shown in Fig.20, a reduction of production costs of 18 % has been achieved by passing over from the mechanized chill casting to the die casting process.

IV. Classification of Metallurgical Semi-Products for the Construction of Vehicles

Semi-products made of aluminium, magnesium and zinc alloys, which are used for the construction of motor vehicles, can be classified from the point of view of alloys utilized and of the casting processes into the following groups :

- semi-products for parts of the chassis
- semi-products for parts of the body
- semi-products for parts of the accessories.

Metallurgical Semi-Products for the Parts of the Chassis

Semi-products for the parts of the chassis are usually mostly produced of aluminium alloys, in some countries of magnesium alloys. They are mostly parts, which are during the running of the vehicle exposed to dynamic stress and must fulfill the following basic conditions :

- to have sufficiently high mechanical values, such as tensile strength, drawing wuality, hardness, impact strength
- to have satisfactory strength when under dynamic stress
- to show only a slight decrease of mechanical values in the range of temperatures, to which the part of the vehicle is exposed when running.

- the walls of most of the semi-products must be entirely homogeneous, so as to avoid the penetration of media when the vehicle is running /lubricants, fuel, cooling liquid, brake fluid/
- dimensional stability is required both during the machining operation and when the vehicle is running, when the temperature and tension are changing
- a good machinability is required, so as to achieve a sufficient between-grind life of machining tools, i.e. practically between the replacements of tools on single purpose machines.

Metallurgical Semi-Products for the Construction of the Body

Metallurgical semi-products - castings - for the construction of the body are of the nature of jewellery. They include parts of the fittings, sometimes the radiator cover, decorative bands etc. For the manufacture of such parts, castings produced by die casting of zinc alloys and galvanized for decorative purposes, have been used already in the past. Recently, to achieve an entirely homogeneous surface of the casting and, thereby, a durable galvanized layer, the cavities of moulds are exhausted to vacuum during the casting operation. The machines used are machines with a warm filling chamber, very often with an automatic cycle. The output of the machines is very high, up to 5000 operations per shift.

In Czechoslovakia, an aluminium alloy Al Mg 9 is used for the metallurgical semi-products of parts of the body, as zinc alloys are wanting. This alloy is easy to polish even without galvanization and it is resistant to the common industrial atmosphere. Examples of castings are shown in Fig. 21.

Metallurgical Semi-Products for the Accessories of Vehicles

Semi-products for accessories, produced by die casting, are, primarily, gasifiers, fuel pumps, and fuel filters. For the production of the aforementioned castings, zinc alloy is used almost exclusively. Castings are being cast by all openings. Only minimum machining operations are needed, mostly trueing off of contact surfaces and cutting of threads for nozzles and plugs. Other parts of the accessories, for the production of which almost exclusively semi-products produced by the die casting process are used, are starters, dynamos, windscreen wipers, heating equipment motors and valves etc. Both aluminium and zinc alloys are used for these purposes. Examples of castings for the production of accessories of motor vehicles are shown in Fig. 23.

V. The die casting process is, generally, characterised by the following advantages :

- a quick production even from a single mould, into which often a set of castings is placed
- the possibility of production in close dimensional tolerances; the castings sometimes do not need to be machined to the final form, and, if machining is necessary, it is always less costly than in the case of castings produced by other processes.
- a smoother surface of castings in comparison with any other casting process
- necessary dimensions of openings are easily achieved /no sand cores are needed/
- the possibility of production of parts of complex forms

- the possibility of production of thin-wall castings /castings produced by die casting compete in that line with pressed work/, the most suitable wall thickness being 0,8 to 4 mm
- extraordinarily low labour costs per one casting
- insignificant material losses
- lower material costs for the production of one casting in comparison with any other method of casting of non-ferrous metals
- easy use of cast-in inserts of other metals or some non-metallic materials;
- the possibility to use a wide range of alloys of the six basic metals : lead, tin, zinc, aluminium, magnesium, copper, and, for the future, it is not out of question to use iron alloys for some simple castings or special uses;
- a relatively easy galvanizing with various metals, due to the smooth surface, and the possibility to use other methods of surface finishing
- a higher strength in comparison with castings produced by sand casting
- the possibility of casting-in attaching links.

The advantages of applying castings, produced by the die casting process, for the manufacture of automobiles, are the following :

- a high dimensional accuracy /slight dimensional deviation/ of single castings makes possible an easy design of fixtures. Simple fixtures are reliable in operation and do not cause difficulties.
- small and uniform machining allowances and a precise clamping make it possible to take a lesser number of cuts during

machining. Dingle purpose machines, event. automatic lines can be designed with a lesser number of units and, therefore, of lesser dimensions and lower capital and operating costs.

- small and uniform allowances make it possible to use in a substantially greater extent internal and external broaching, which represents a modern and economic method of machining
- small dimensional differences between the single castings and the possibility of easy clamping enable the designer to choose the dimensions of a part according precisely to the stress, to which it will be exposed, without reserves for the uneveness of the casting walls. When using the die casting process, walls of a lesser thickness can be cast without difficulties. The lower weight of parts thus designed contributes to the reduction of the weight of the whole vehicle.
- for the production of castings by die casting, it is not necessary to employ qualified founders. Modern casting machines eliminate the influence of the human factor on the quality of castings almost entirely. The floor spaces, needed for the production of castings, are reduced in comparison to classical processes approx. to 50 %.

VI. The disadvantages of the die casting process are, in general, the following ones :

- the production costs of the mould are rather high. Even so, they are often lower than the costs of other production tools. The costs are generally outweighed by the economies in machining and by other economies

- the die casting process can be, up to now, used generally only for castings of alloys of non-ferrous metals, and of a lesser number of non-ferrous metals than the sand casting process
- it is not suitable for some kinds of castings, where sand cores must be used because of the form of cavities, and which can be produced by gravity casting
- the castings are always to a certain extent porous, even if the porosity can be controlled in acceptable limits, if vacuum casting is not used. The porosity increases in relation to the wall thickness
- the maximum dimension of castings is limited by the dimension of the casting machine
- the die casting process involves considerable capital expenses for the casting machines and other equipment
- this process of casting requires certain experiences, so that only qualified labour can be employed.

A thorough evaluation of various production processes often results in favour of the die casting process, if another process of casting, drop forging, cutting on an automatic lathe or even pressing was considered

The following disadvantages of the die casting process concern especially its applying in the production of automobiles :

- the production of steel moulds, necessary for the die casting process, requires a specially equipped workshop and qualified tool-makers. The life of the moulds is limited to 8000 up to 200000 operations. The moulds must be therefore restored. It is therefore economic to carry out the modernization of vehicles in cycles, corresponding to the cycles of the renewal of the moulds.

- the preparatory operations for the die casting process are more exacting as far as concerns the qualification, knowledges and technical standard of technicians than the classical methods.

VII. Economic and Technical Comparison of the Die Casting Process with Other Production Methods

Chill Casting

In comparison with castings produced by chill casting, castings produced by the die casting process are much more advantageous, because a greater number of alloys can be used, and it is possible to attain more accurate dimensions, smoother walls, more complicated cores, thinner walls and a greater speed. The casting costs are higher for chill casting, but the costs of the mould are lower, even if its life is shorter and the maintenance more expensive. A casting produced by the die casting process usually has better mechanical properties of surface layers than a casting produced by chill casting of the same alloy, which, on the other hand, is not so porous. Sand cores can be used for the production of castings by chill casting to achieve forms which cannot be produced by die casting. They are, however, relatively expensive, as they must be prepared individually for each casting.

Sand Casting

If we compare the die casting process with the sand casting method, we must take into consideration, primarily, that for sand casting a new mould or core must be prepared for every single casting or a set of castings. Further, patterns and pattern plates are necessary, which are, however, much cheaper than moulds for the die casting process. Moulds for the die casting process have a life of about 8000 operations

/for aluminium alloys/ and after depreciation are much more economic than sand moulds. Castings produced by the die casting process have a smoother surface and more accurate dimensions than castings produced by sand casting, and almost every dimension and every kind of opening can be produced, whereas by sand casting, only relatively great and unaccurate openings and recesses can be achieved. Castings produced by die casting thus do not need to be machined to such an extent. Moreover, thinner walls can be achieved, the casting speed is much greater and the mechanical properties of castings are better in comparison with castings produced by sand casting of the same alloys. On the other hand, iron can be used for sand casting, and the dimensions of castings are practically unlimited. Grey cast iron and other iron alloys, used for sand casting, are less expensive than non-ferrous alloys, which are necessary for the die casting process. Labour costs are much higher in the case of sand casting than for die casting.

If we compare castings produced of the same kind of alloy, our own experiences show, that by changing over to the die casting process, metal consumption per casting can be reduced by 10 to 20 %, the same quality of castings being maintained. Apart from the reduction of metal consumption, operational costs in the foundry, especially for cleaning, were reduced by 15 to 30 %. In comparison with chill casting, the economies are similar, especially as far as the reduction in metal consumption is concerned.

Lost Wax Process or Combustible Model Casting

In contrast to the die casting process, even alloys of high-nelting metals, especially iron, nickel, cobalt, can be used, for which the aforementioned method is mostly used, although even such alloys, which are used for the die casting process, are convenient. The minimum th ... can be achieved, the minimum diameter of openings can be 1 mm, the weight of steel castings seldom overpasses 5 kg /recently, it increases/.

Tolerances of dimensions are greater than for the die casting process, e.g. 0,15 % for steel, mechanical properties are excellent. The most complicated forms can be produced, which cannot be produced by any other method. The costs of the moulds are considerable, about 60 % of the costs of moulds for die casting, operational costs are relatively high and costs for the finishing of castings are low.

Production of Parts by Sintering of Metal-Powders

For the production of constructional parts, iron powder is used most frequently, the cost of which is higher in comparison with steel, but lower than for non-ferrous metals. There is an advantage, that there occurs no waste. The production rate is considerable, even 1200 pressed parts per hour, which must be, of course, sintered. Small parts of conventional forms can be produced by this process, the forms being less complicated than the forms of castings produced by the die casting process; the dimensions are limited by the power of the press. Wall thickness can be even less than 0,7 mm. The quality of the surface is approx. the same as when the die casting process is used. The accuracy of dimensions and the strength are, at present, better than with aluminium castings. The costs of the pressing tools are approx. the same as the costs of moulds.

Drop Forging

Many parts, produced by drop forging, can be produced by die casting as far as the form is concerned. Castings can, however, not compete with forgings, as far as mechanical properties are concerned /small brass parts are an exception/. For the production of small parts we prefer casting because of the greater accuracy of dimensions, the possibility of achieving thinner walls and core openings, which can be provided on forgings only by machining. The costs of drop dies are the same or slightly higher than the costs of moulds for the die casting process, and their life is shorter. Forged materials have, however, better mechanical properties than cast materials, even if the material is the same. For drop forging we therefore choose most frequently cheap steel, which has very good mechanical properties.

Stamping of Steel Sheets

In comparison with stamping, the costs of tools for the die casting process are lower, the castings can be of more complicated forms, a lesser number of assembling operations in comparison with stamped parts is needed, and the dimensions are more accurate. The single parts of the products can be changed more easily. Products of non-ferrous metals are more corrosion-resistant than steel sheet. On the other hand, the production by stamping is usually faster, cheaper and more easily procurable steel can be used, a higher strength of products can be achieved at the same weight and smaller wall thickness. The stampings are not porous, they have a smoother surface and can be handled with less care than castings produced by the die casting process. Other conditions, which can influence the choice between die casting and stamping, must be judged individually by the designer according to the form and application of the product. It is clear from this comparison, that castings produced by the die casting process, can compete with stampings only in relatively few cases.

Machining on Automatic Machines

Many parts produced on automatic lathes can be equally well and at lower costs be produced by the die casting process. Even if we compare steel parts, produced on automatic machines, the costs of castings produced by the die casting process are usually lower because, notwithstanding the higher price of the non-ferrous alloy used, the loss of material, occuring during the machining of bar steel, is usually balanced by the reduction of material consumption for casting. In most cases, castings are not so strong and their surface is not so smooth as with machined parts, but often this difference is not decisive, sothat some castings can compete with parts produced on automatic machines, even if they are provided with a thread, because even a thread can be produced by casting. Many machined parts have to be additionally treated, e.g. tapers and grooves or bored holes must be milled, whereas the same parts produced by the die casting process do not need any additional machining, with the exception of cleaning-off of flashes. If it is necessary to machine castings, the chips can be melted anew in the workshop and used for further casting, whereas chips from automatic machines have a much lesser value.

Plastics Moulding

By the die casting process, almost all shapes of mouldings can be produced. Plastics moulding does not, however, enable such a complexity of shape of the product, as can be achieved by die casting. Moreover, a part produced by the die casting process, is more strong at the same thickness of walls, it can be produced with more accuracy, according to the results of impact tests it is less brittle and has a better dimensional stability than a plastic moulding. Moulds for the production of plastic mouldings are usually more expensive than moulds for casting. The speed of die casting is always higher than the speed of plastic moulding. Plastic mouldings are non-conductive, they are corrosion-resistant, they do not need surface finishing and, for the same dimensions, they are lighter.

VIII. Economic Evaluation

When designing new motor vehicles and plants for their production, event. before their reconstruction, it is necessary to carry out an economic comparison of both variants of the production of semi-products. We compare both the costs which do not depend on the number of demi-products produced, and the costs which do depend on the number of semi-products produced. We take into consideration, if special equipment necessary for the technological processes which are being compared, will be consumed entirely, or if its service life is greater than the amount of semi-products produced. If the equipment is consumed entirely, the result of the economic comparison has a form shown in Fig. 23. If the number of semi-products produced is lower, than the service-life of special equipment, the graphical result of the economic comparison has the form shown in Fig. 24.

IX. Adaption of Shape of Parts, which are to be produced by the Die Casting Process

To achieve good economic results and a high quality of castings produced by the die casting process, it is necessary to adapt the shape of castings, when changing the technology of casting, e.g. when passing over from gravity chill casting to the die casting process. The adaption of shape of newly designed parts must be carried out on the beginning of design work. The maximum efficiency of these adaptions can be achieved only in close co-operation of the designers of the vehicle with specialists in die casting, and specialists in machining. From the point of view of casting technology, the adaptions of shape necessary for the achievement of good technological results, can be divided into the following three groups :

- shape adaptions necessary for good technological results in the production of moulds :
  an example is shown in Fig. 25. The mould cavity for a hand-wheel according to Fig. 23a can be produced in such a way, that a tracing model is prepared by hand and the shape of the cavity is traced according to it. The shape of the cavity according to Fig. 23b can be prepared by turning and boring, that means without the use of the expensive tracing model
- shape adaptions necessary for good technological results of the casting proper :
  an example is shown in Fig. 26. With the casting shown in Fig. 26a, the free shrinkage of the casting is prevented by the massive flange on the one side and on the other side only by the core of the mould, which has a relatively small diameter. This condition results in the core being cut off by the considerable shrinking force. By adapting the shape according to Fig. 25b, i.e. by adding two massive projections beside the core, the shrinking force affects the projections and the core is not stressed by this force.

shape adaptions necessary for achieving good technological results in the cleaning of castings ;
an example is shown in Fig. 37.
According to Fig. 37a, both openings in the place of contact of cores are of the same diameter. The film, which arises on the area of contact of both cores, cannot be removed by simply shearing it off. It will be necessary to choose a more complicated operation or to finish the opening by hand. When one of the diameters is increased according to Fig. 37b, the film can be removed by simply shearing it off on a press.

When considering shape adaptions, it is necessary to respect the operational costs of the whole part. Sometimes the shape adaption reduces the costs of the initial steps of the production, whereas the costs of the later phases of production can be greater than the economies in the initial step. Sometimes it is opposite. Therefore, a close co-operation of all interested is very necessary to attain the single object : to reduce the total costs of the finished part of the vehicle.

X. The Use of Cast-in Parts of other Materials than the Casting Material

The disadvantage, that it is up to now impossible to use iron alloys currently for the die casting process, can be frequently overcome so, that we select a suitable light-metal alloy as the raw material and we cast in a steel screw or a brass sleeve etc. The condition which must be always ensured is a safe deposition of the part during the casting operation. E.g. steel screws cast in light-metal alloy castings are shown in Fig. 38. According to Fig. 38a, the screw is hold in the longitudinal axis by means of an auxiliary core, in other cases shown the screws are prevented to change their position by passing the whole thickness of the casting wall. Between the casting wall and the threaded part, there is left a cylindrical part without threads. It is necessary to leave this part smooth to prevent the alloy to fill up the threads of the screw. The removing would be expensive. A section of a casting with cast-in screws is shown in Fig. 29. A sleeve of self-lubricating sintered bronze, cast-in in a light metal alloy casting, is shown in Fig. 30. The shape of the casting according to Fig. 30a does not ensure a safe detention of the cast-in sleeve. It is necessary to make adaptations according to Fig. 30b. The increased core will represent a supporting surface, which holds the sleeve safely during the casting operation.

Pulleys of crankshafts are very often designed for the use of vehicle motors according to Fig. 31. The V-groove is formed of sheet-steel stampings, connected by spot welding. The whole is cast on aluminium-alloy hubs. Both steel parts, forming the V-groove, are provided with carrying openings. During the casting the opening is filled by the alloy, which upon shrinking acts with a great force to ensure the carrying of the steel-stamping by the aluminium hub.

XI. Machines for the Die Casting Process

The demand for an enhancement of the quality of castings produced by the die casting process not only led to a greater activity in the field of development and research of the casting technology, but it also called for the increase of the technological convenience of the function of casting machines.

The main conditions, with which the functions of the machines must comply, are the following ones :

- the machines must enable a perfect clamping of the two halves of the mould even when the overall height of the mould is changing due to thermal expansion of the mould. This condition is fulfilled in machines with a mechanical hinged closing device, with four guiding pillars
- the machine must be designed for a continuous control of the speed of the filling piston, in all three phases of its movement, i.e. the closing of the filling opening, pre-filling and filling.
- the machine must be designed for a continuous control of the filling force, i.e. the control of the pressure on the alloy during the filling of the cavity mould
- the set filling force must attain its maximum value in a time shorter than 0,03 sec. after the complete filling of the mould cavity by the alloy
- the machine must be designed so as to enable the setting of all necessary values of all steps of the casting process. The set values must be reproduced during further casting only with negligible deviations
- the machine must be designed for an automatic casting process including an automatic control of the dosing furnace, automatic cleaning and lubrication of the mould, automatic stripping of castings from the mould, automatic placing of parts to be cast-in, automatic control of the mould temperature.

In order to enhance the wuality of castings produced by the die casting process, the specific pressures on the alloy during the filling of the mould cavity have been increased. This trend corresponds to the results of development works. For a safe clamp of the mould halves, a greater closing force in necessary for the same dimensions of the castings. The good quality of the castings made it, however, possible to produce castings of greater dimensions and, consequently, of a greater weight. That issues in greater dimensions of the machines. Up to 1939, the greatest machines for die casting had a closing force of 500 Mp. As a unique machine, a machine manufactured by the company Polák with a closing force of 1000 Mp has been tested. The aforementioned post-war development led to a subsequent increase of the closing force of the greatest types of machines to 1500 Mp /Triulzi, Milano - Italy/, 2000 Mp /2000 t of the US made machines of the company Dohler-Jarwis, Toledo, USA/, 2500 Mp /Vinterlat, USSR, and a range of other machines, such as Triulzi, Votan VWF Düsseldorf etc./. A machine with a closing force of 3500 Mp is about to be finished /Votan-VWF Düsseldorf/. A modern machine for the die casting process is shown in Fig. 32.

The individual manufacturers produce machines in a certain series of closing-force values. E.g., the following range is being produced : 160, 250, 400, 630, 800, 1000, 1600, 2500 Mp. For the foundry, it is advantageous to be equipped by machines only from one manufacturer and with a minimum possible range of sizes. Thereby, the need of spare parts and the maintenance costs can be considerably reduced. We prefer machines with a greater closing force. We try to place in the mould a greater number of castings of lesser dimensions, so as to achieve a full exploitation of the machine. It is, however, possible to produce castings of greater dimensions. It is not necessary to be apprehensive of the designing of moulds with a greater number of castings, which are sometimes called multi-cavity moulds. The aforementioned research and development works concerned the problems of multicavity moulds and set up principles of a correct design of moulds. From the point of view of economy, multicavi moulds are advantageous. By their introduction, the following costs are reduced :

- labour
- costs of special tools /moulds/
- material melting costs, the melting losses /a better exploitation of the liquid alloy/
- depreciation and interests of machine and construction capital costs.

All these economies result in a reduction of overall costs of the production of castings.

Modern machines for the die casting process are designed as hydraulic machines. They are of electrohydraulic design, the electrical part of the equipment being contactless. Incombustible liquids are used as driving media, which are winning over commonly used hydraulic oils. The combustibilityof these oils is a source of serious hazzards in the foundry and its surroundings.

Modern machines are well equipped with apparatuses which prevent injury of the attending workers. These equipments have the following functions :

- they prevent the hot melted alloy to burn the attending workers, if it eventually spatters out of the mould or the filling chamber
- an equipment which prevents a spontaneous confusion of the single steps of the casting process. The set sequence of the steps is blocked in such a way, that the next step can follow only after the foregoing step has been completed

- an equipment which prevents a spontaneous movement of any part of the machine or the mould /the closing of the mould, the movement of the filling piston, if the attending worker could be endangered by such a movement/.

XII. Principles of Establishing the Optimum Size of a Die Casting Machine

The alloy represents during the filling of the mould and of the filling chamber a metalloplastic system. Measurements, which have been carried out in the scope of already mentioned research work, have shown, that the specific pressure on the alloy in the filling chamber is only negligibly reduced during the transfer to the cavity of the mould. The static nominal filling force increases, however, very intensively, when the mould has been entirely filled. The kinetic energy of the filling mechanism evokes upon the filling of the mould and, consequently, upon stopping of the movement, an increase of the pressure, the so called pressure peak. The height of this peak depends on the speed of the movement of the filling piston. The metalloplastic system "filling chamber - mould cavity" is diagrammatically shown in Fig.29. In the metalloplastic system, the pressure of the alloy evokes during the filling a force, which acts against the filling force of the machine. The greatness of this force is given by the projection of the surface, which is affected by the alloy pressure. This force must, however, be always lesser than the closing force of the machine, so as to prevent the spattering of the alloy. The indicated relation is applied for the establishing of the optimum magnitude of the closing force of the casting machine. It is valid :

$$P_Z = \frac{Po}{k}, \quad \text{where}$$

P_Z = nominal closing force of the machine /Mp/

Po = maximum opening force of the machine /during the pressure peak/ /Mp/

K = safety coefficient, where 0,8 suffices

The relation is, of course, valid only under the condition, that both forces act in the same axis. It is, therefore, necessary to place the projection of the surface affected by the alloy pressure so, that the centre of gravity of this surface be on the axis of the closing force of the machine.

An undispensable condition of an economic production of high quality castings by the die casting process are well designed and perfectly manufactured moulds. It is, therefore, necessary to give attention to the design of the moulds and to the technology of their production. The service life of moulds depends on the alloy, which is being cast. It is very short for copper alloys, attaining approx. 10000 operations. For aluminium and magnesium alloys, it is 80000 to 200000 operations, and for zinc alloys it is the highest one, 500000 up to 1,000000 operations. It is therefore necessary to renew the produced moulds. The capacity of mould production must correspond to these requirements. Great attention must be given to the equipment for a complete treatment of the active parts of the moulds. A mould for casting the cylinder block is shown in Fig. 33.

XIII. Conclusion

The quantity of castings for motor vehicles, produced by the die casting process, is steadily increasing. Castings will be subsequently used for other parts, which are up to now produced by classical technologies. It concerns e.g. aluminium cylinder heads, which are produced by the die casting process in two parts, connected by cementing or welding and subsequently machined together. An assiduous development of the technology of die casting, of the machines, furnaces and other foundry equipment, which is carried out on many places in the whole world, brings about further improvements of the production process and a continuous enhancement of the quality of castings.

In a whole range of organisations throughout the world, development problems are being solved with the goal to improve the technology of the die casting process, the improvement of machines and other equipment. The results of this work are apparent in an ever increasing quality of the castings, which makes possible to apply them even in such cases, where parts, produced by other classical processes, have been used up to now.

Fig. 1

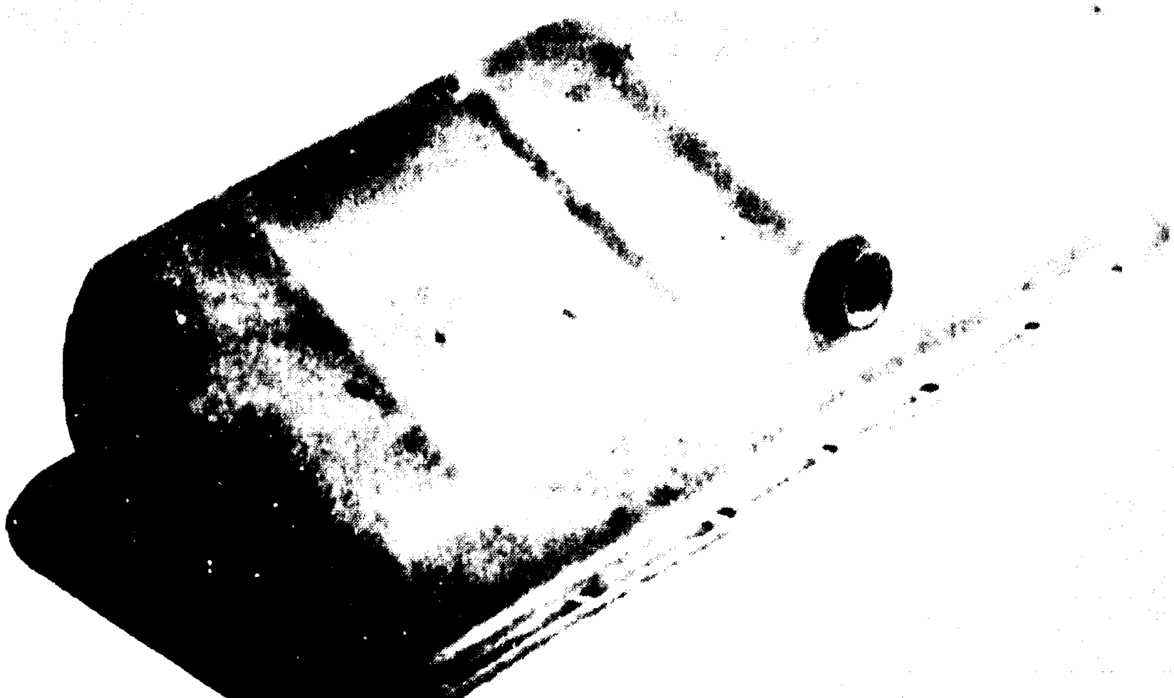
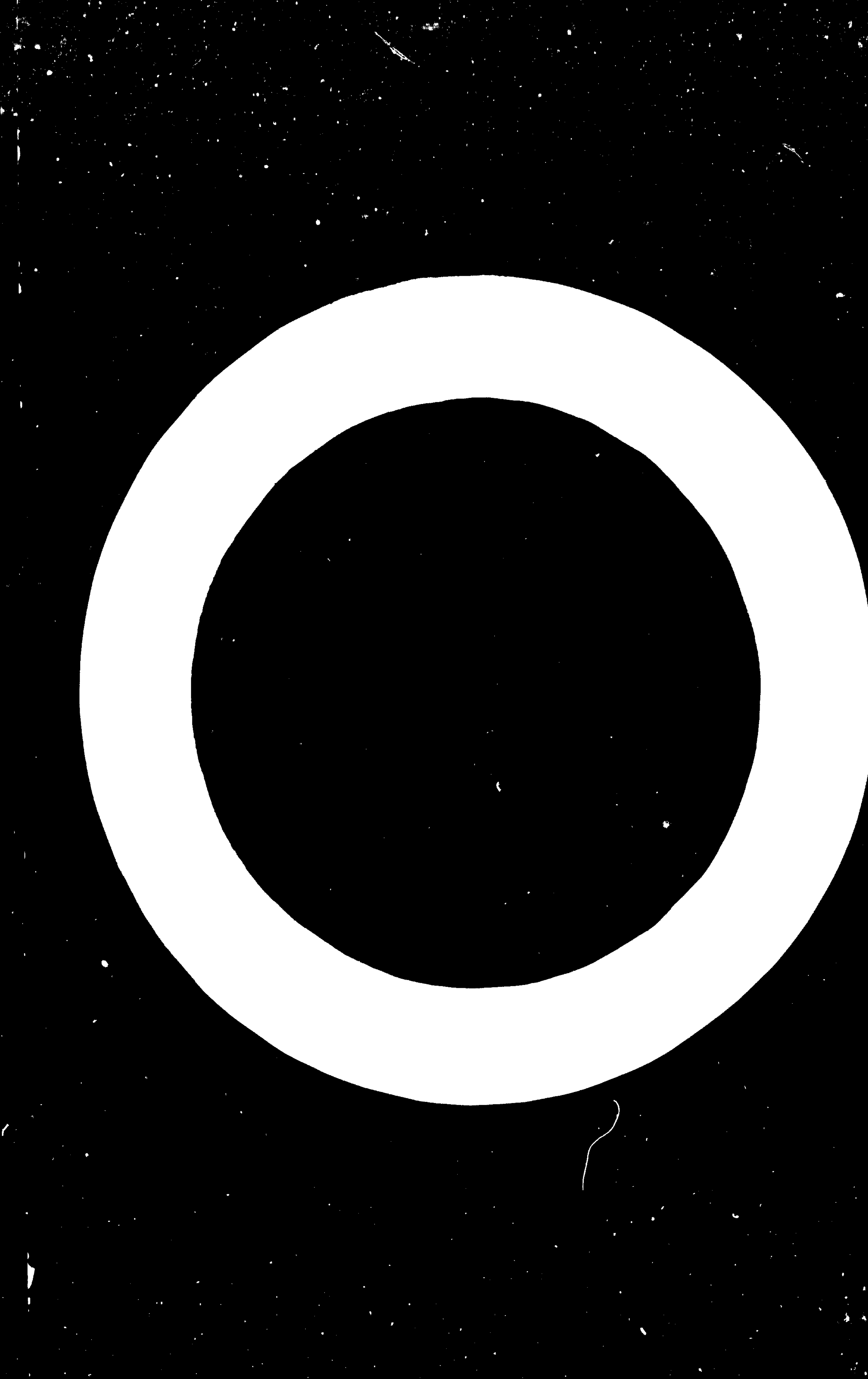


Fig. 2



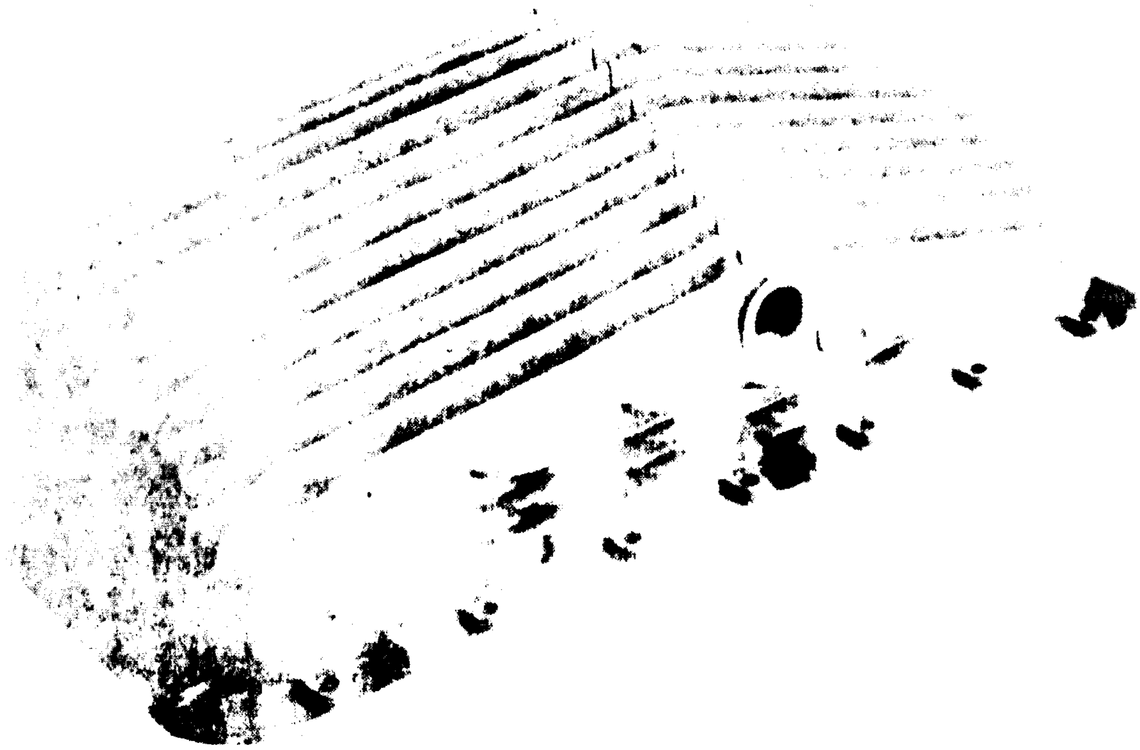


Fig. 3

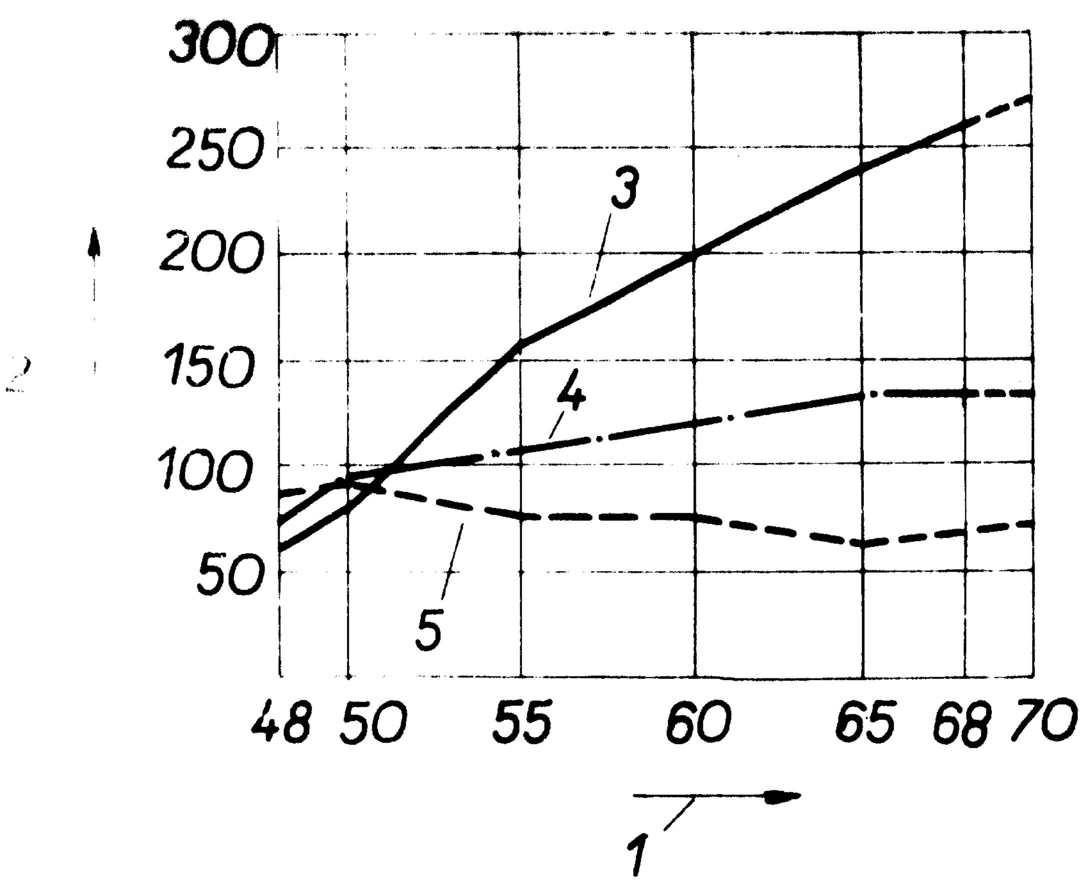
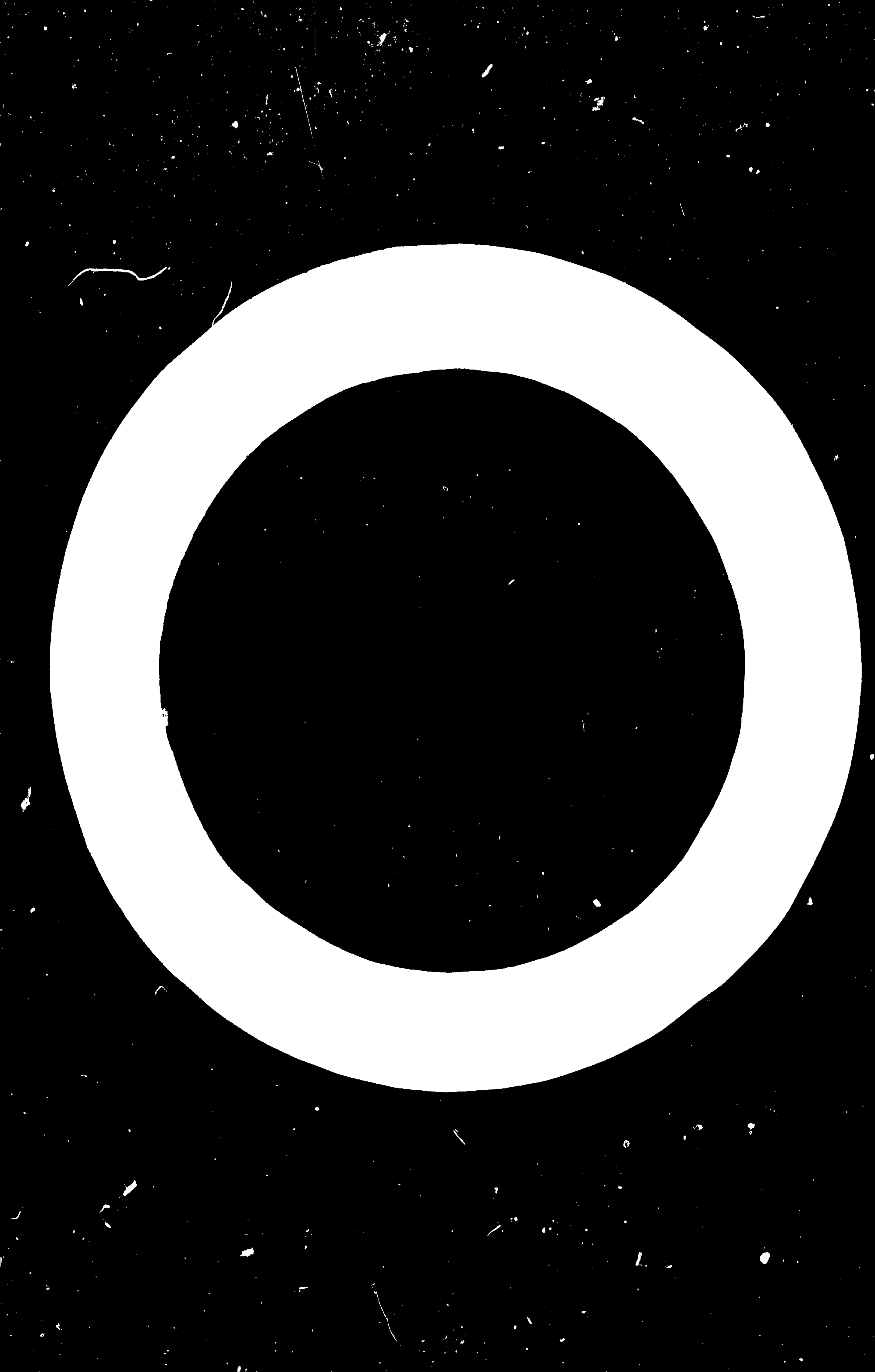
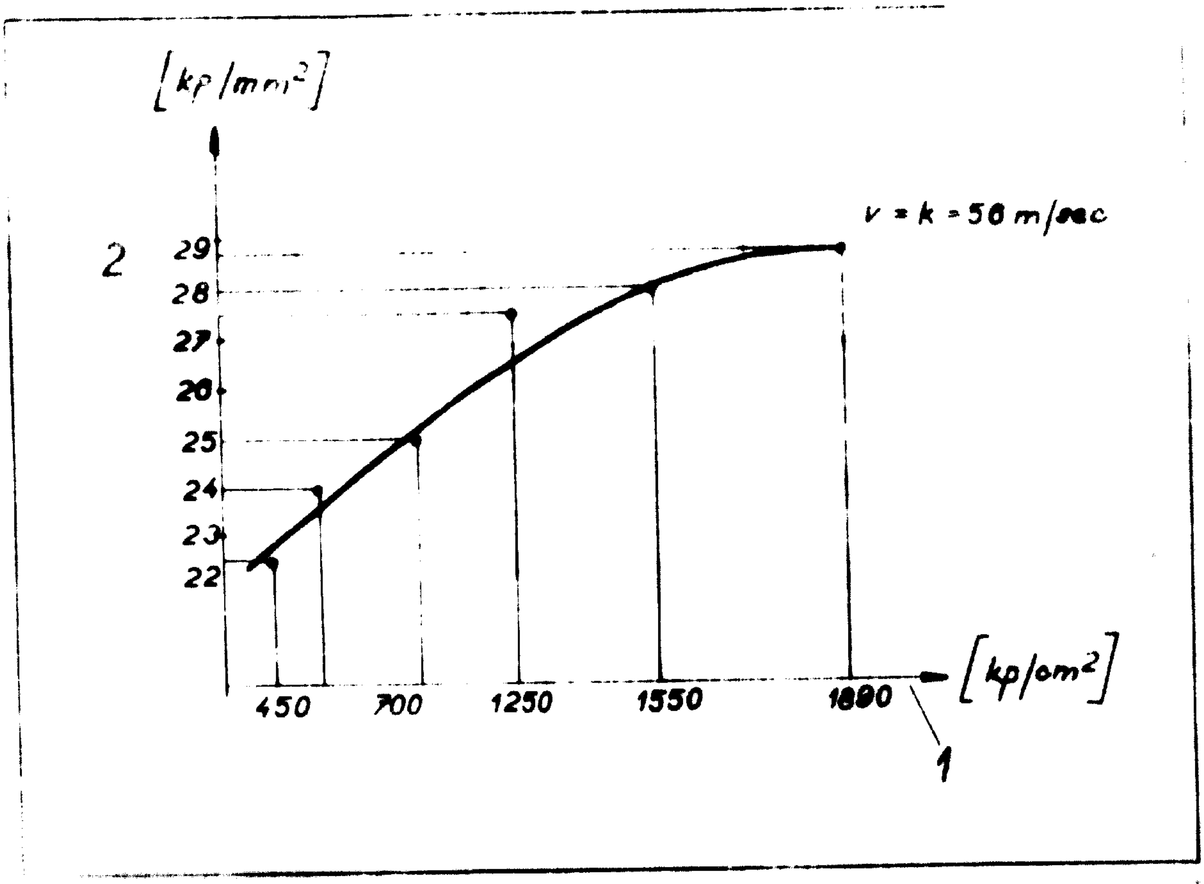


Fig. 4

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v = k = 56 m/sec
2
29
28
27
26
25
24
23
22
450
700
1250
1550
1890
[kp/cm²]
1

Fig. 5

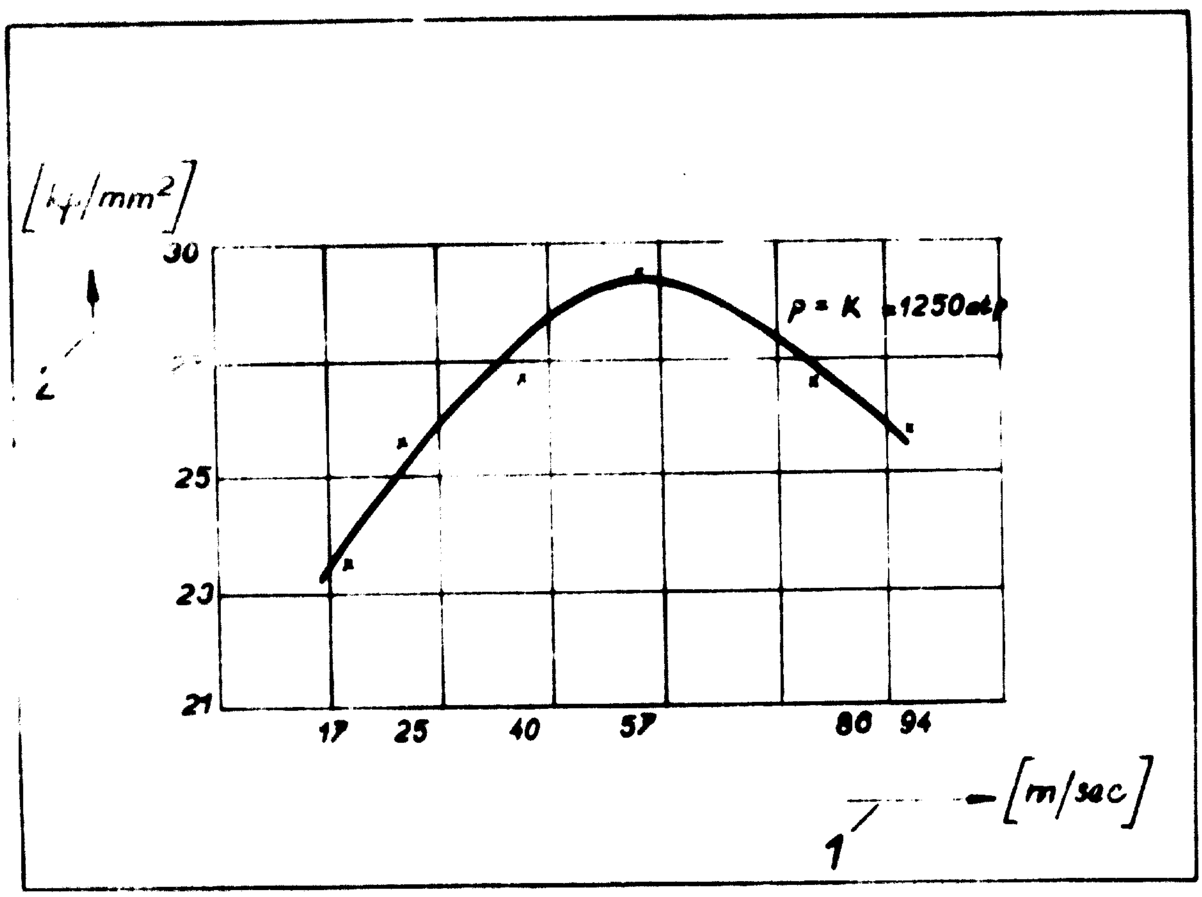
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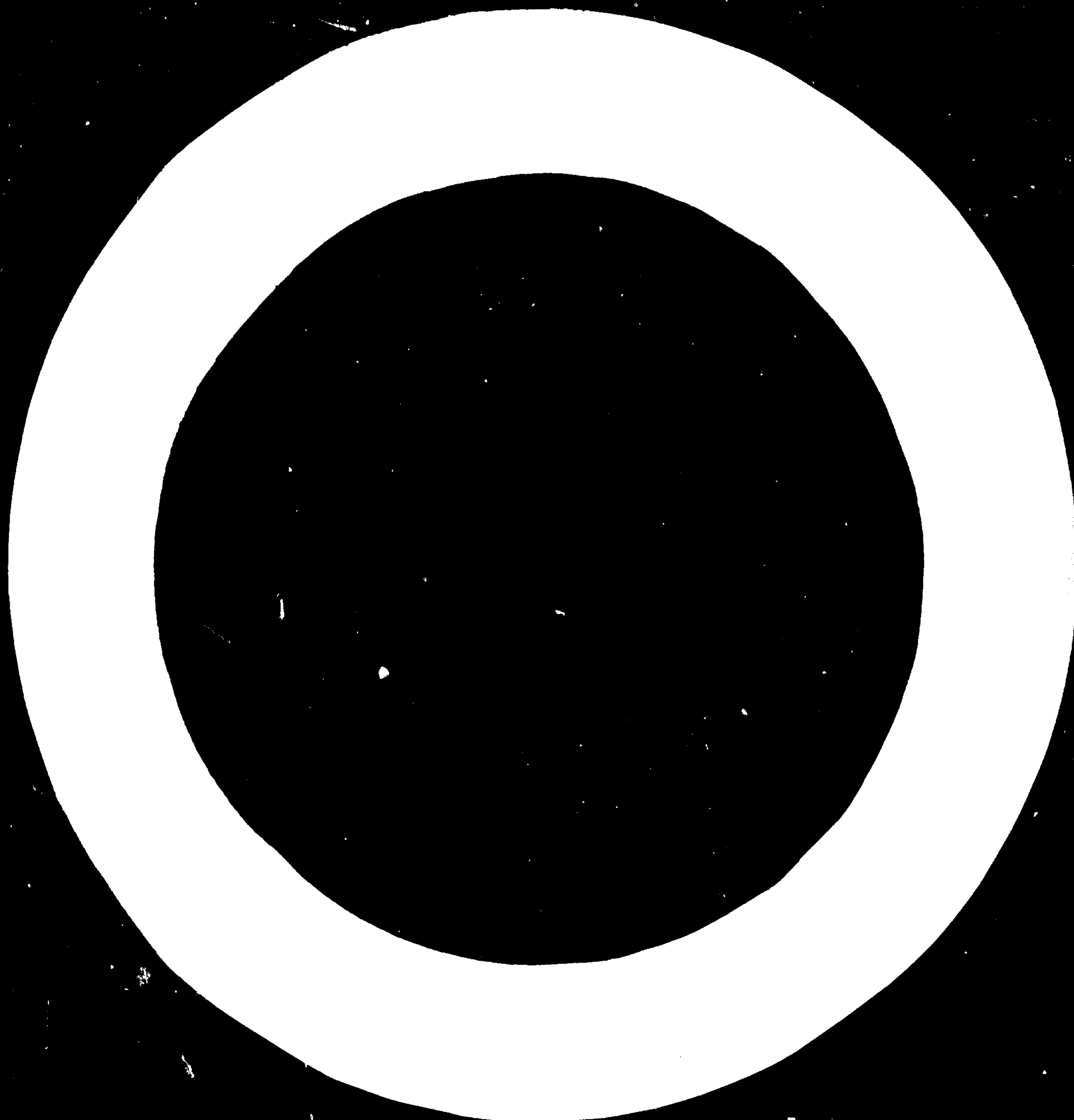
Fig. 6



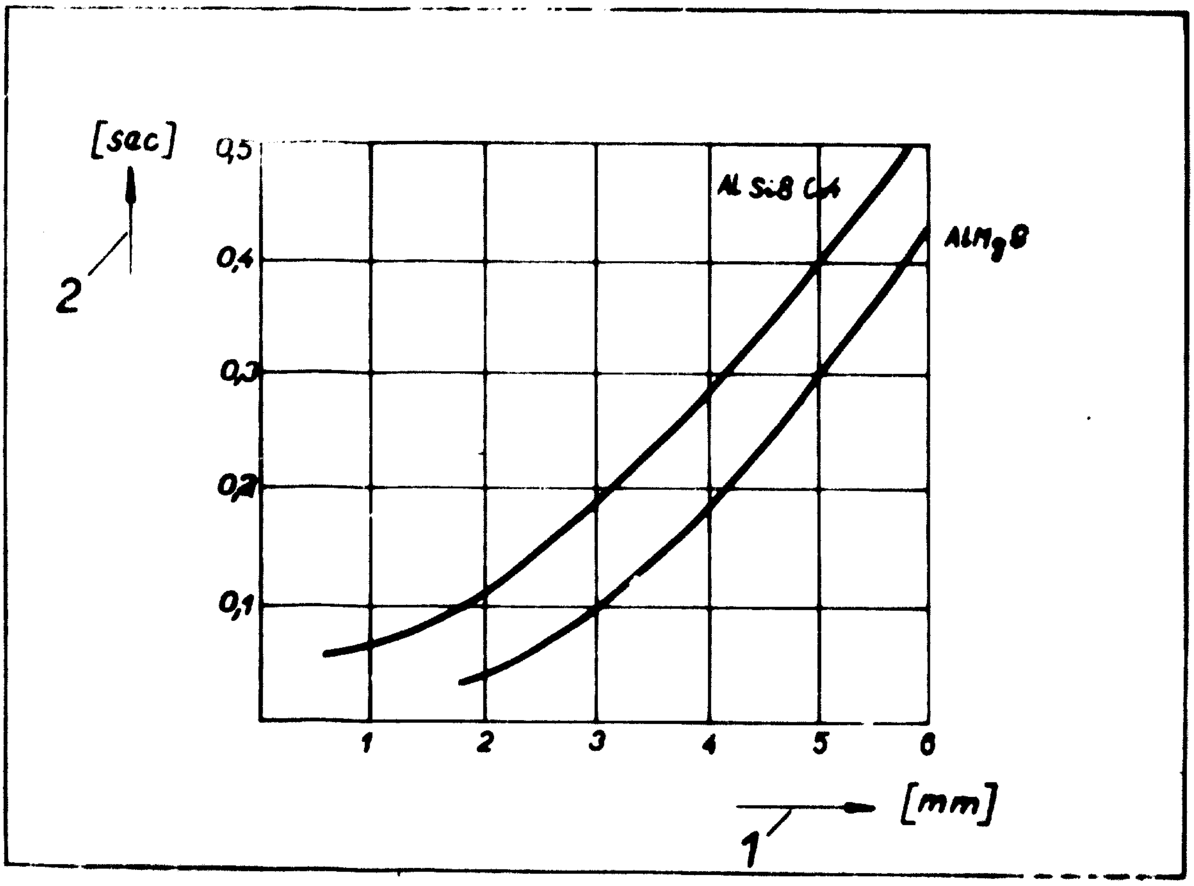

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Fig. 7

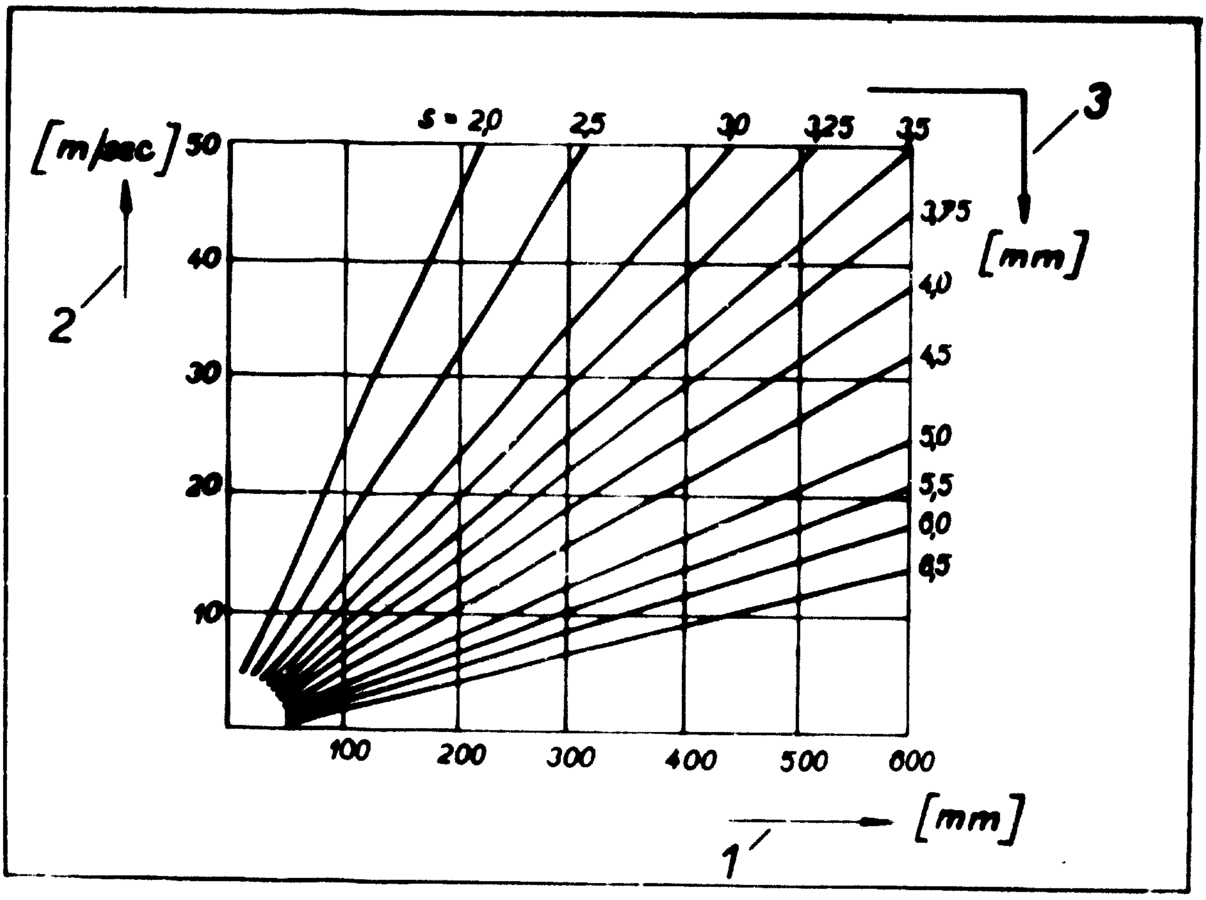
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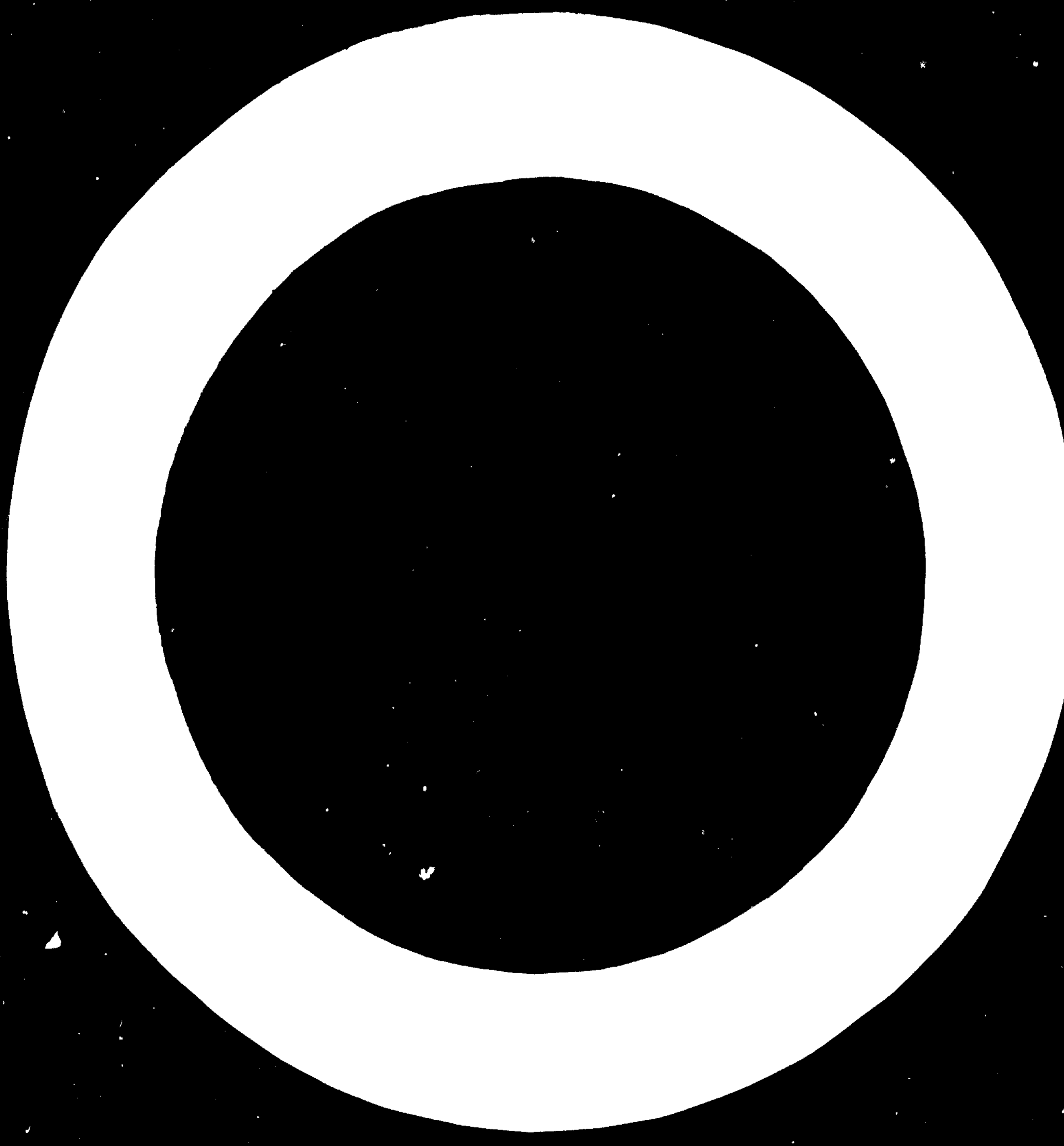
Fig. 8



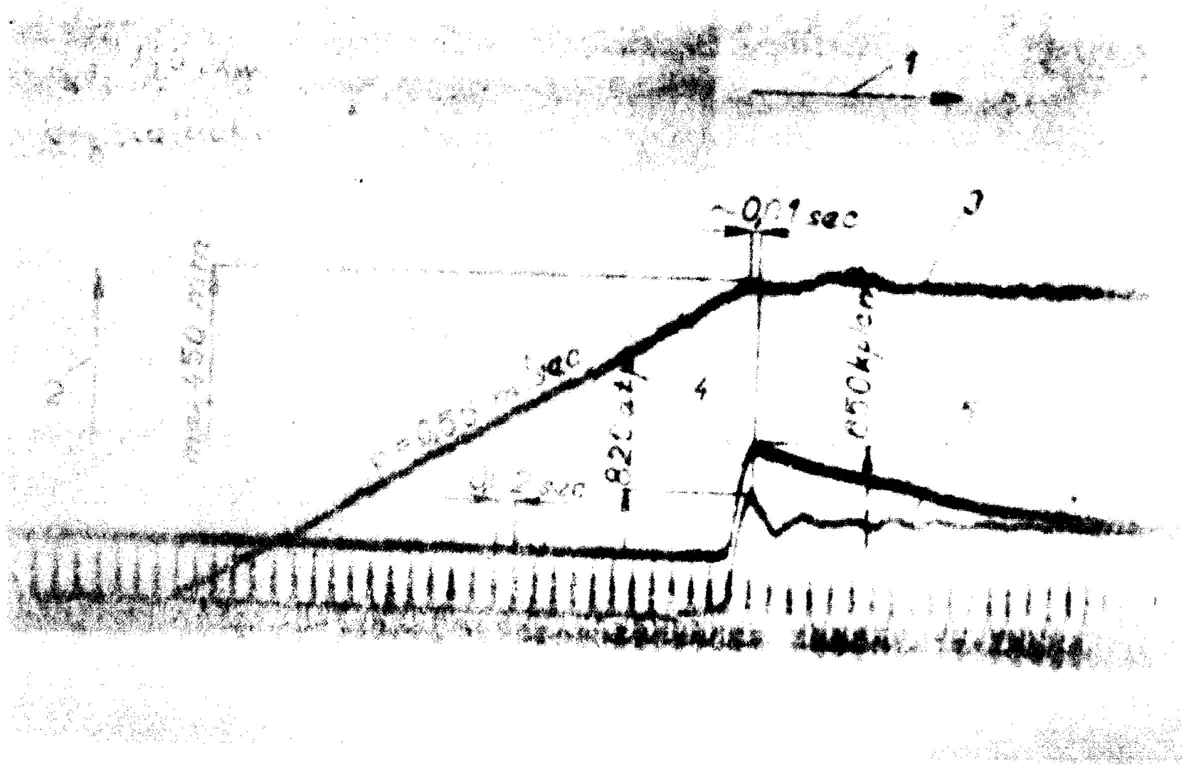


Fig. 9

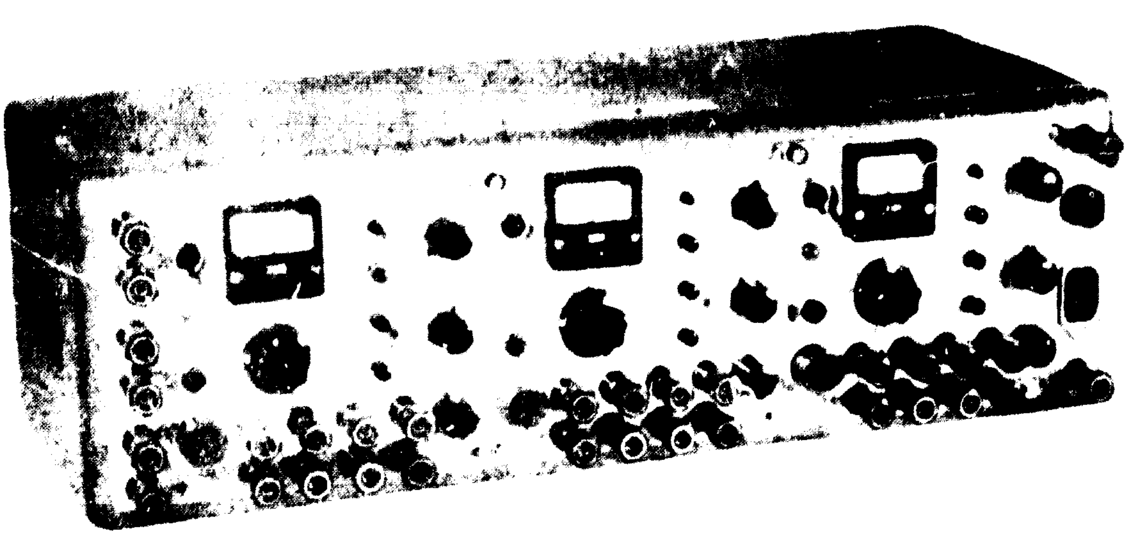


Fig. 10

Fig. 11

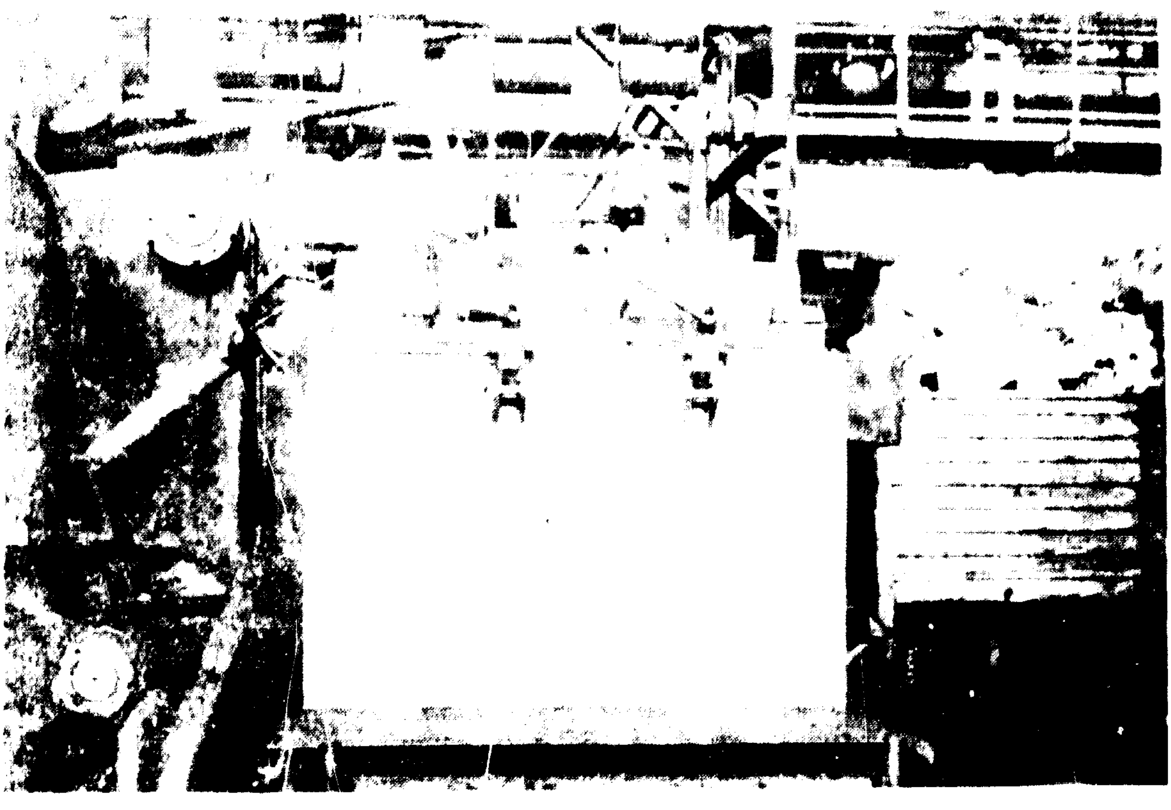


Fig. 12

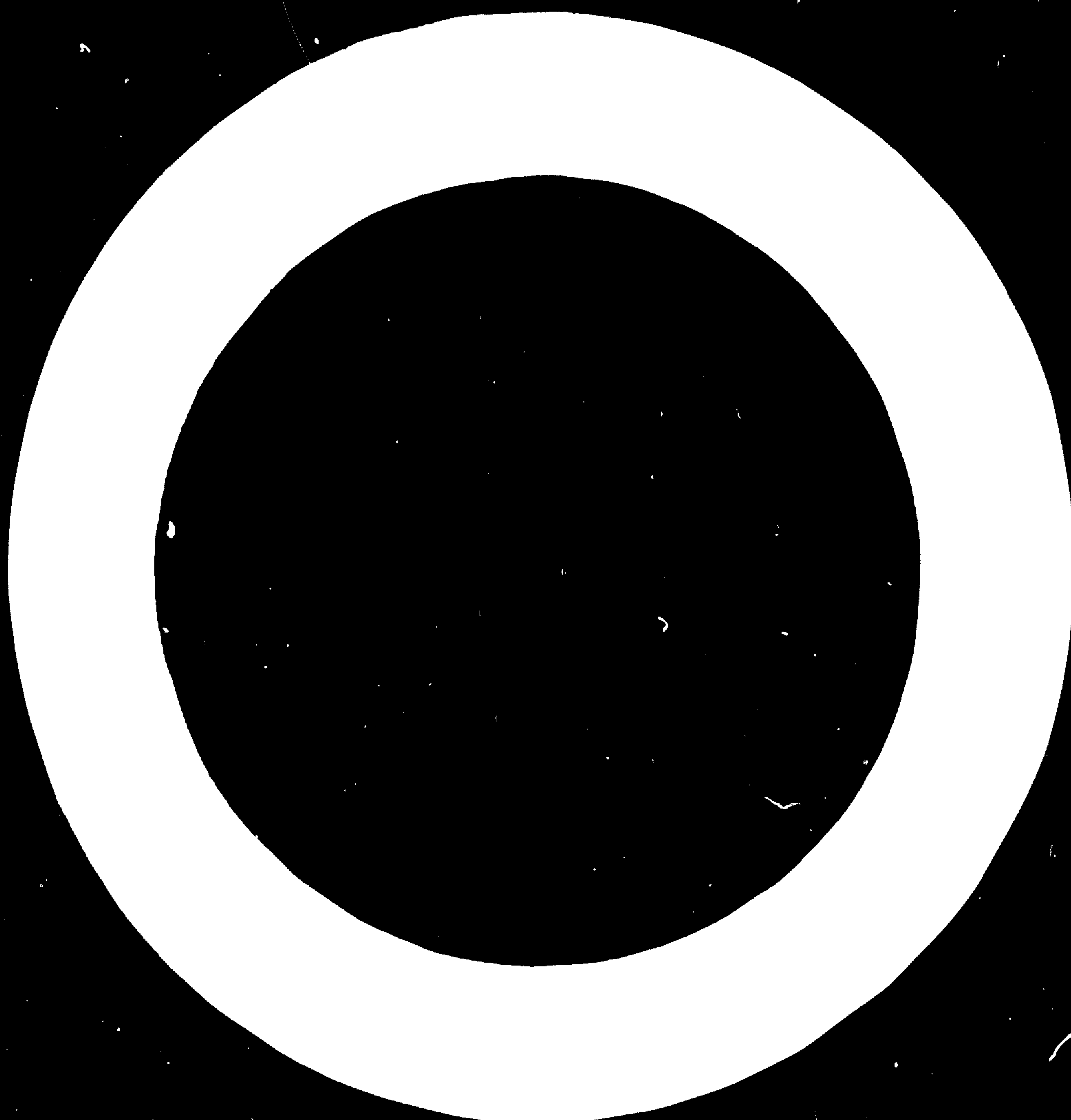


Fig. 13

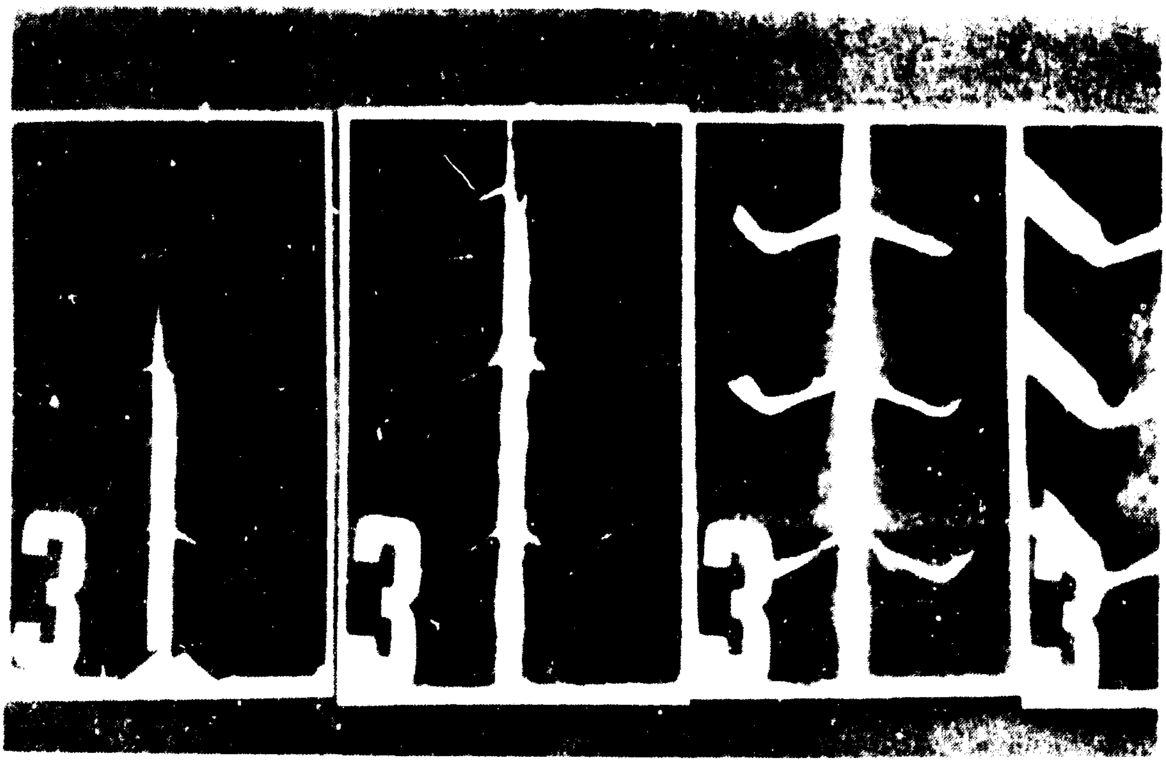
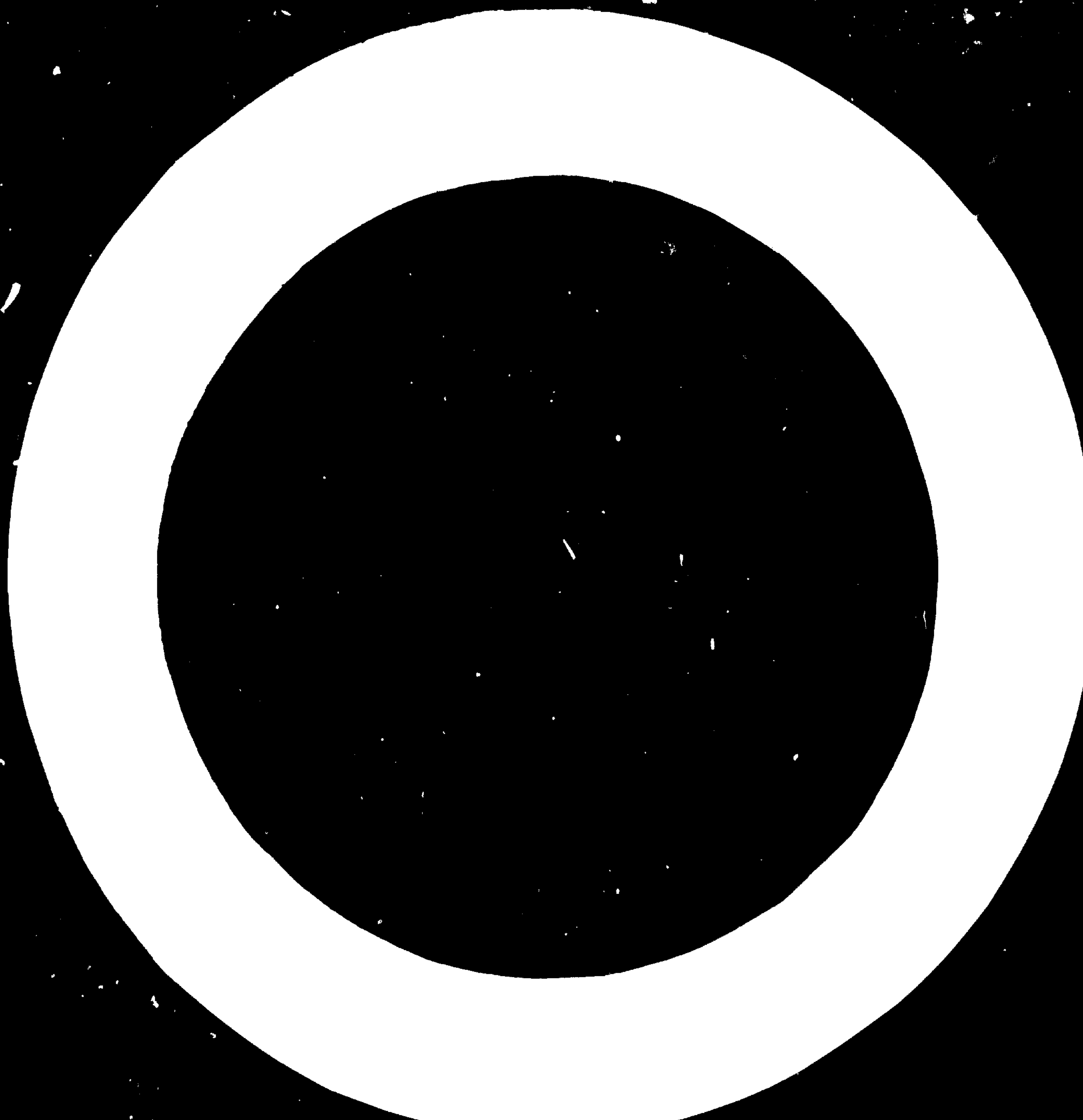


Fig. 14



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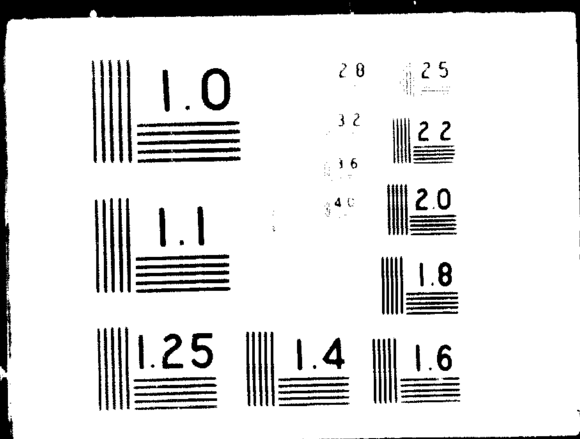


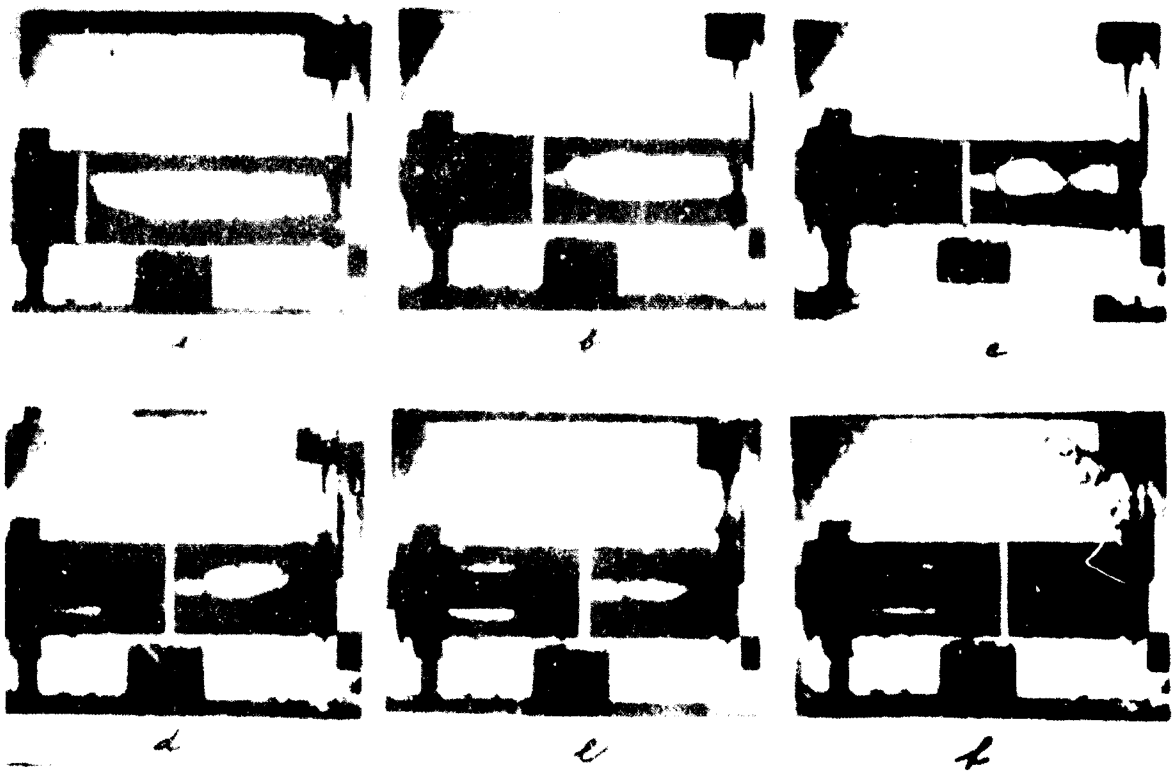
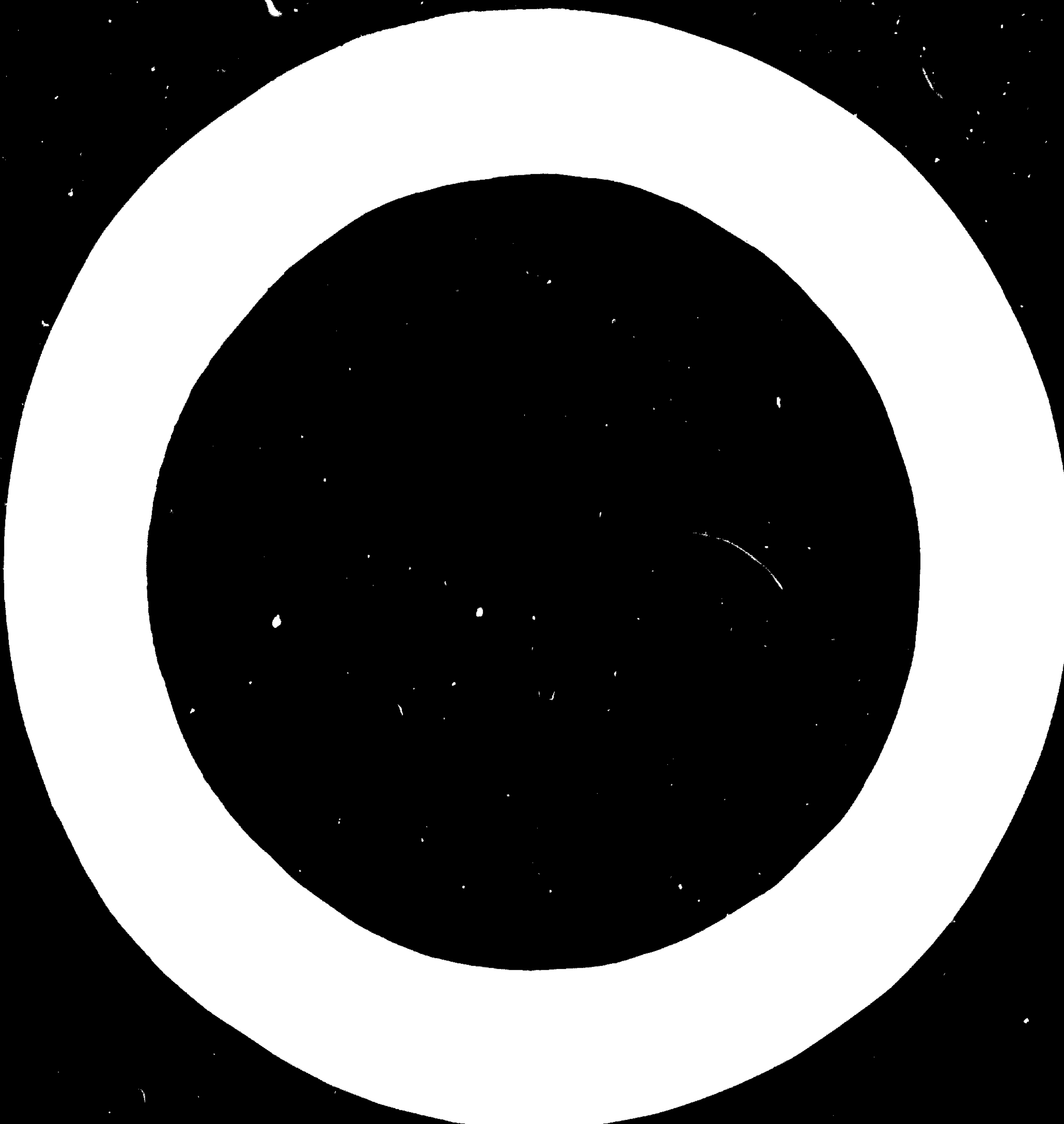


Fig. 15

Fig. 16

Fig. 17

Fig. 18



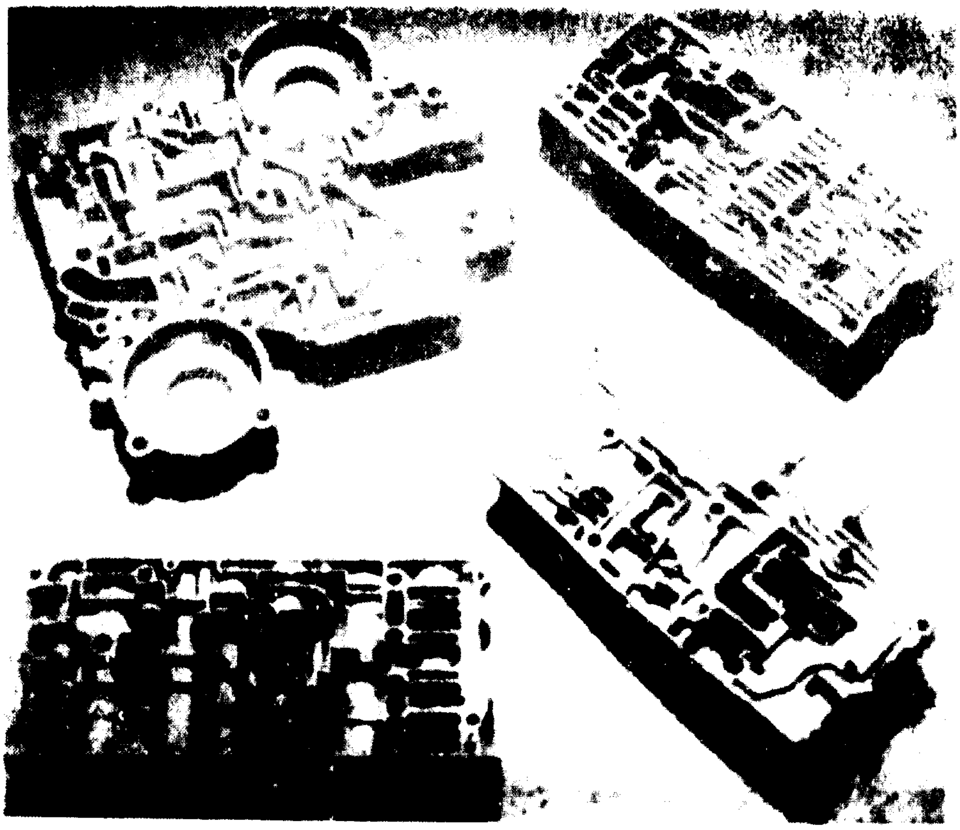
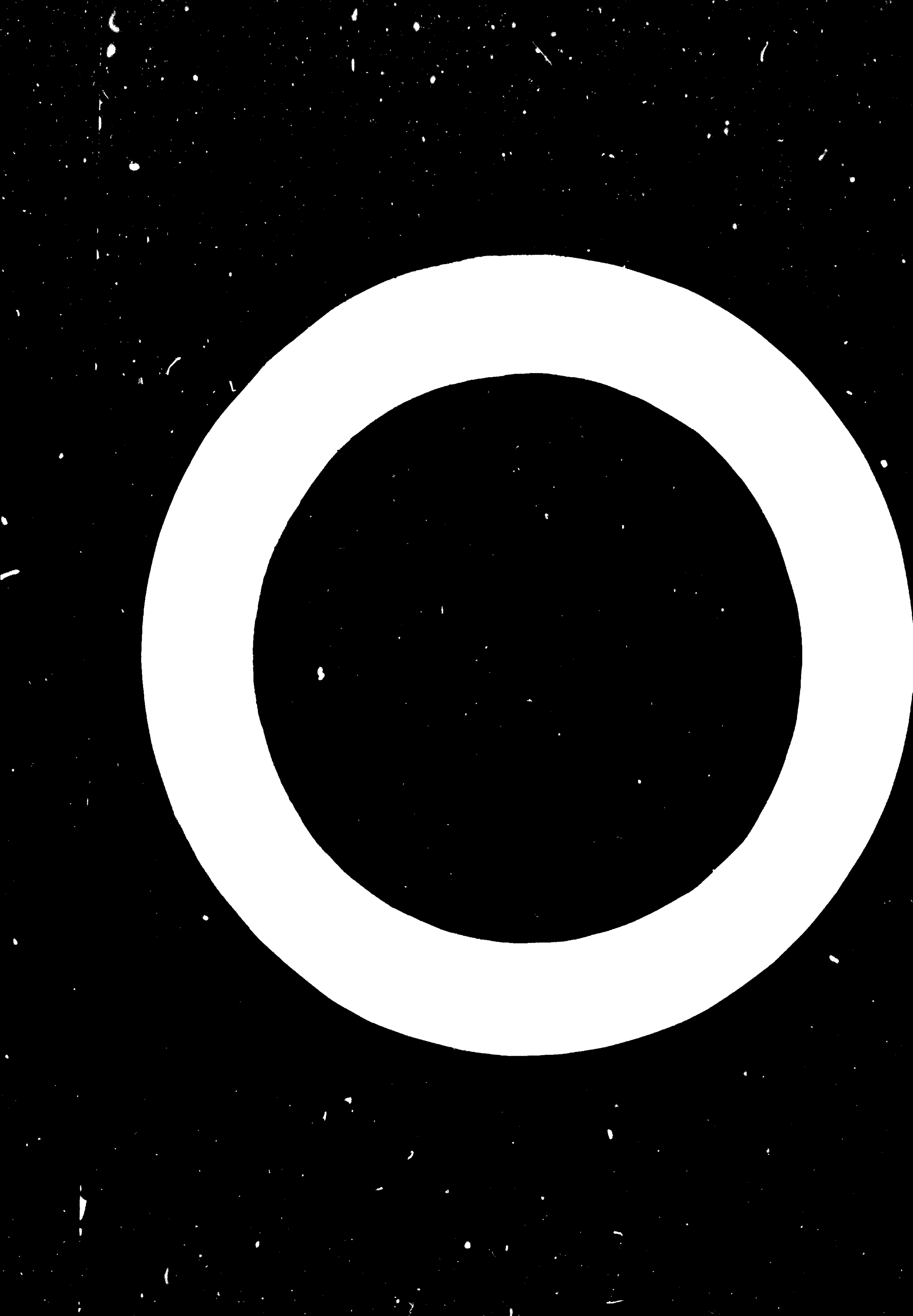


Fig. 19

Fig. 20



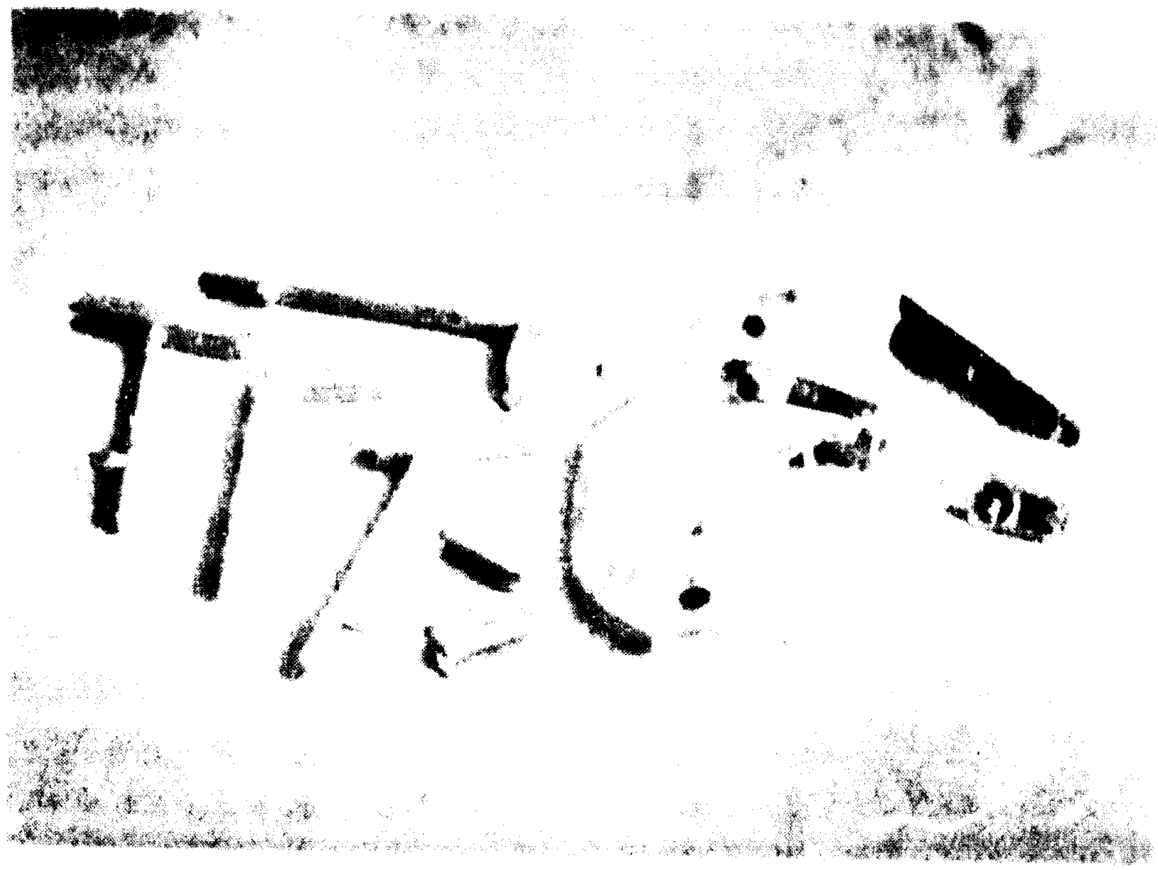
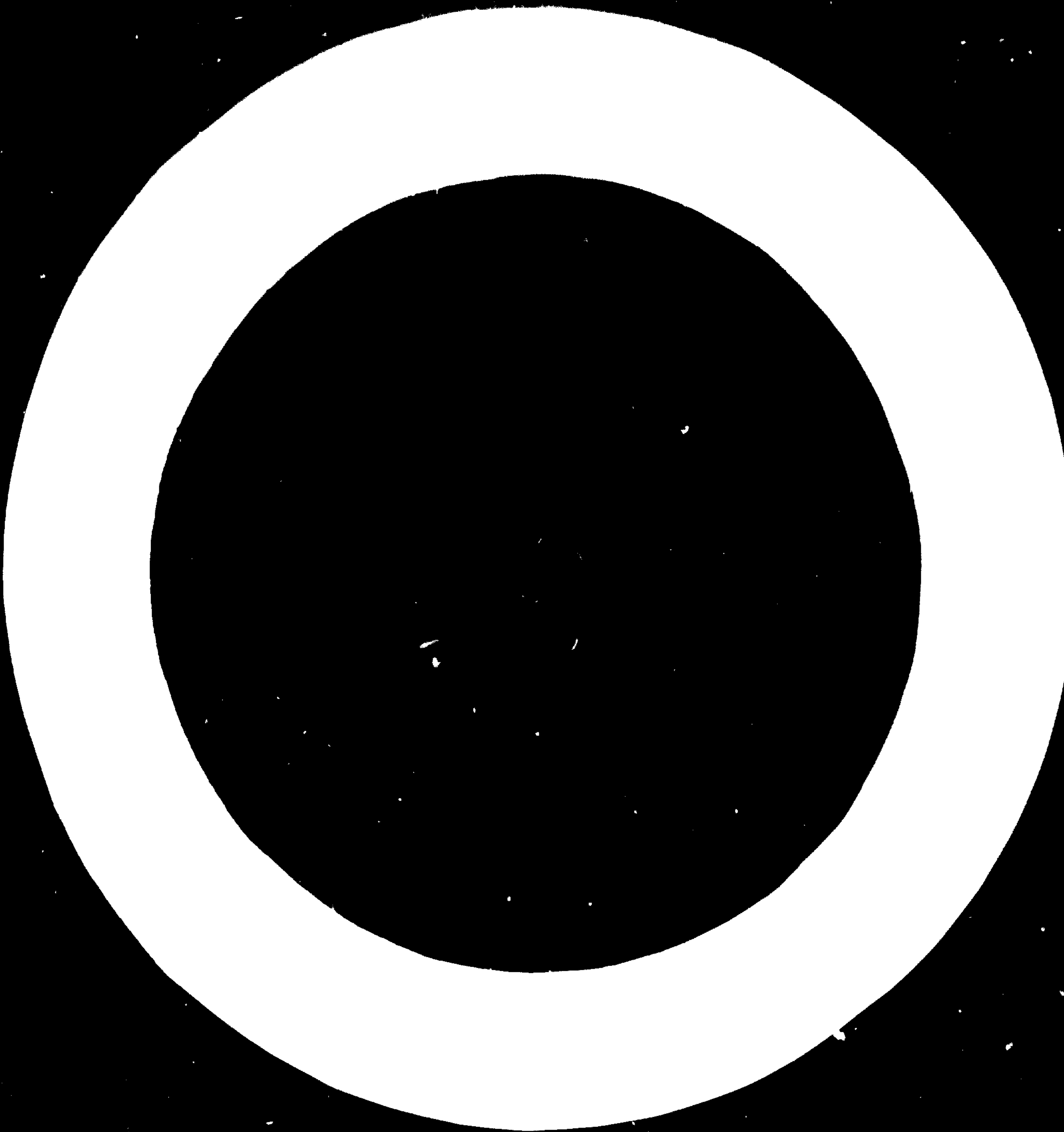


Fig. 21

Fig. 22



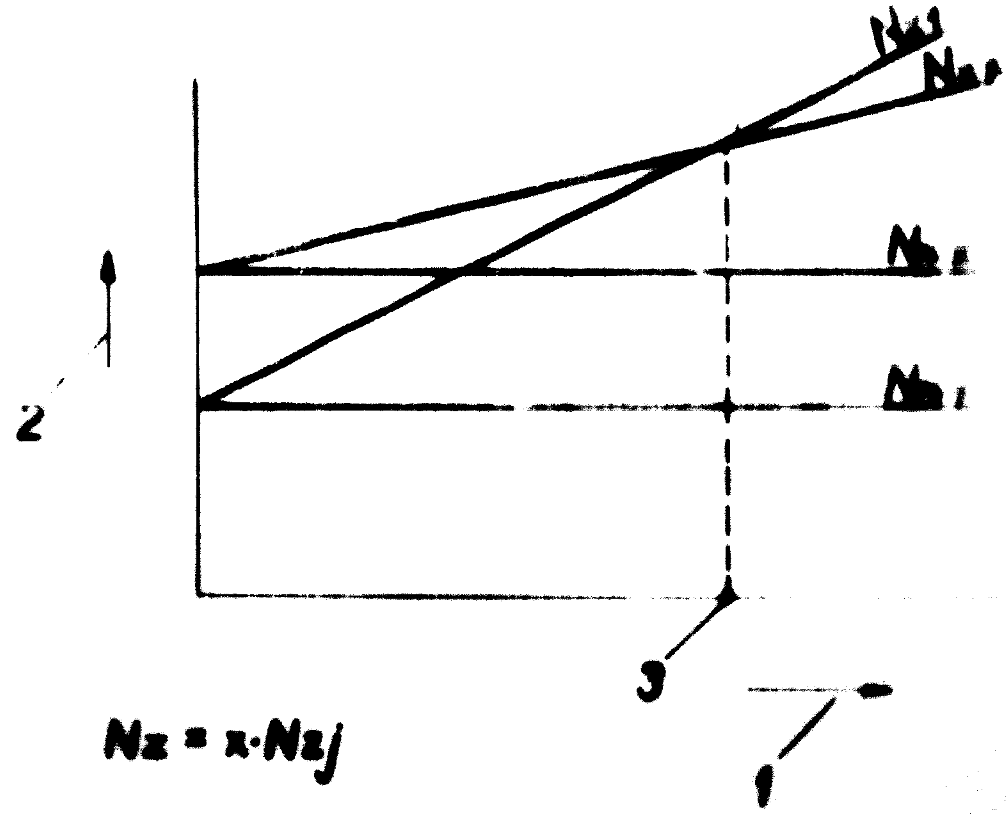


Fig. 23

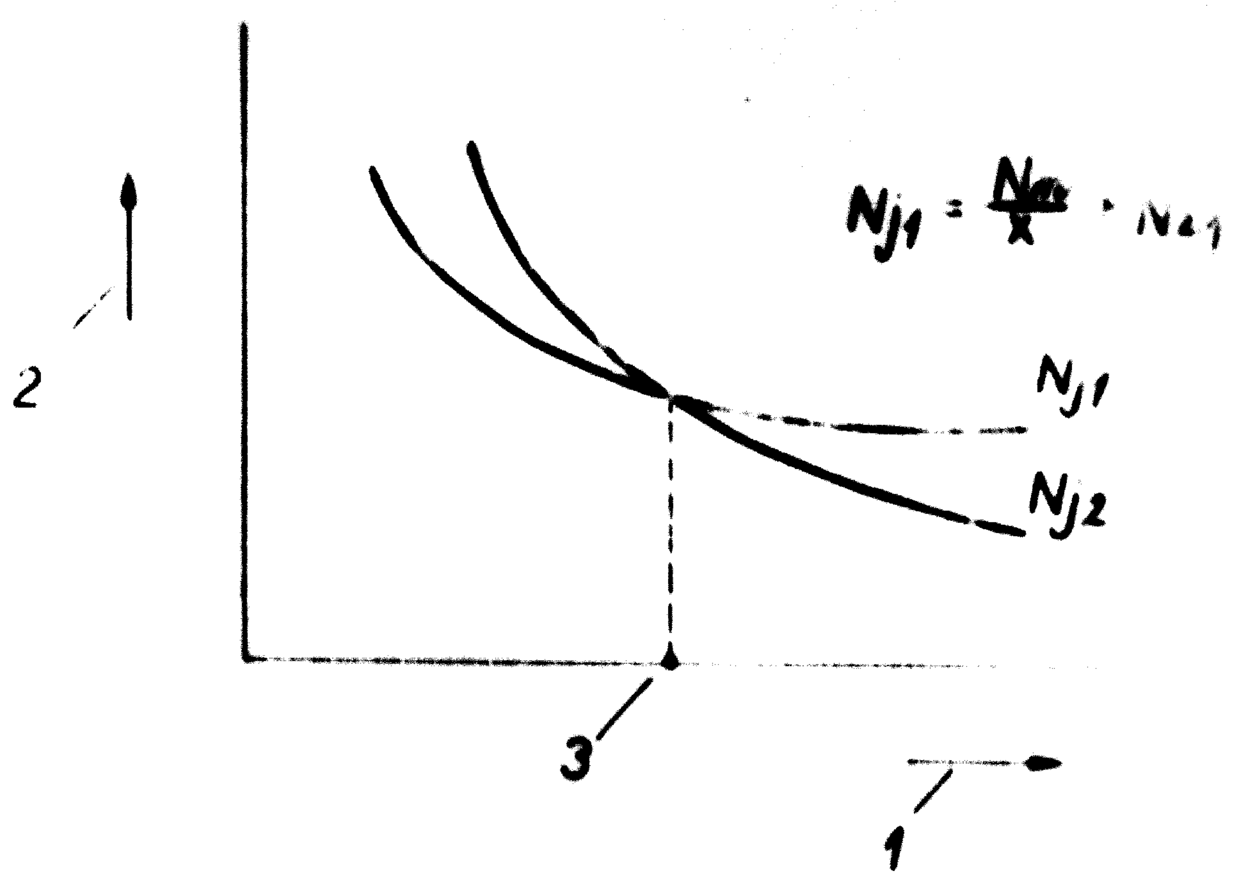


Fig. 24

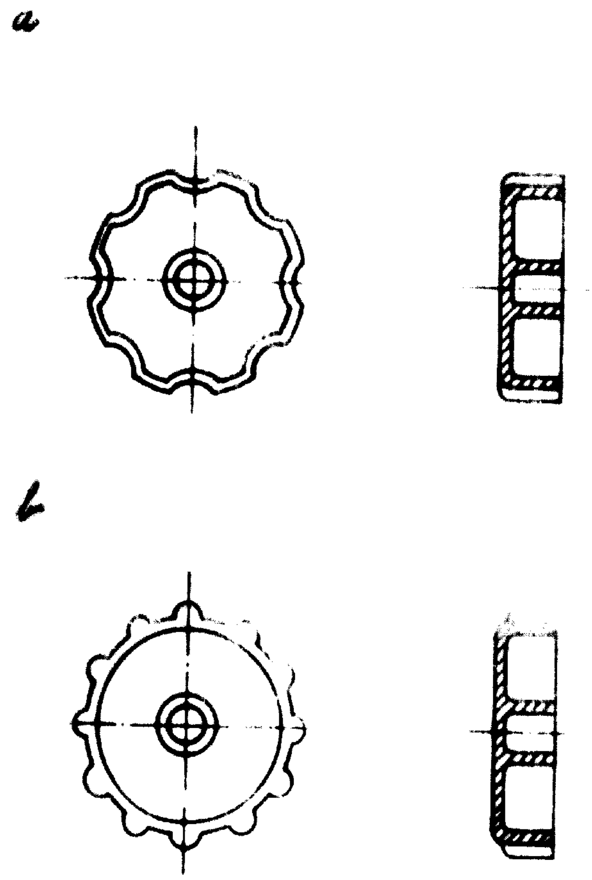
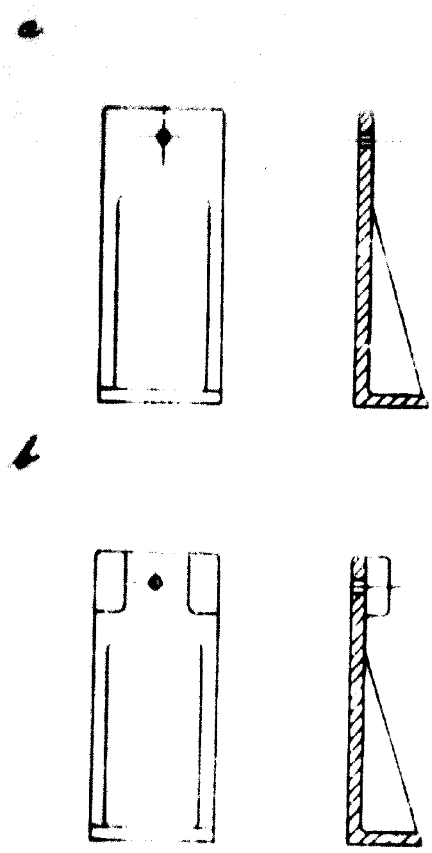


Fig. 25



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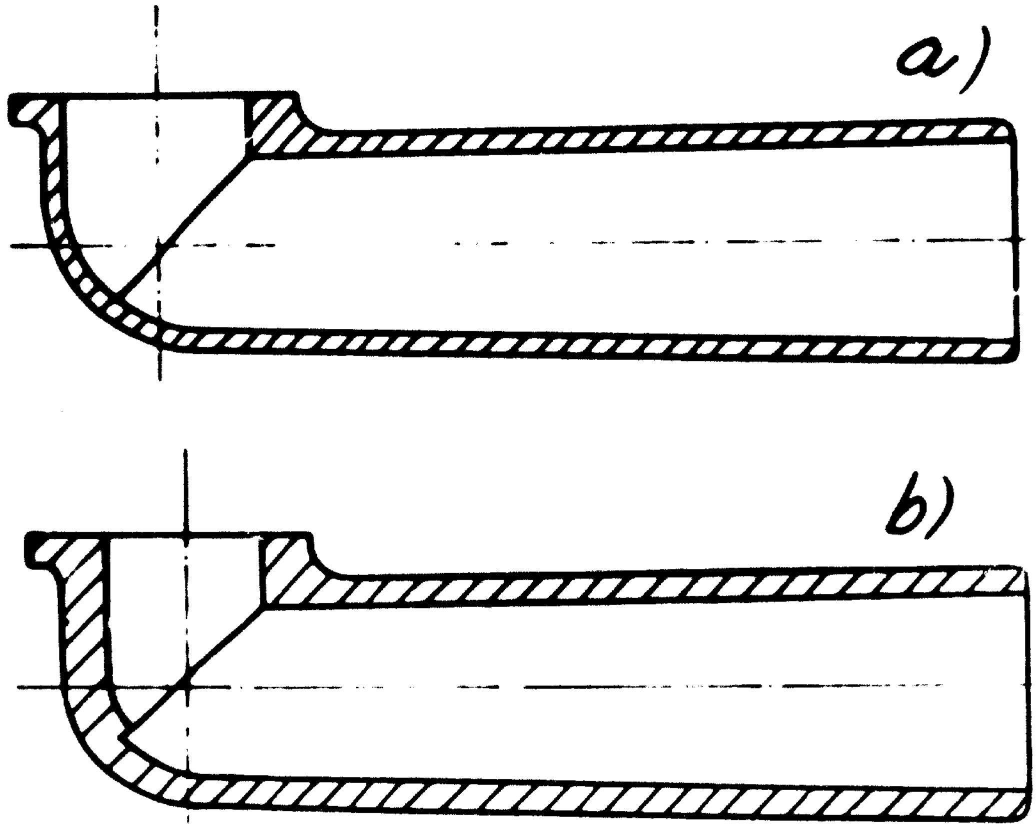


Fig. 27

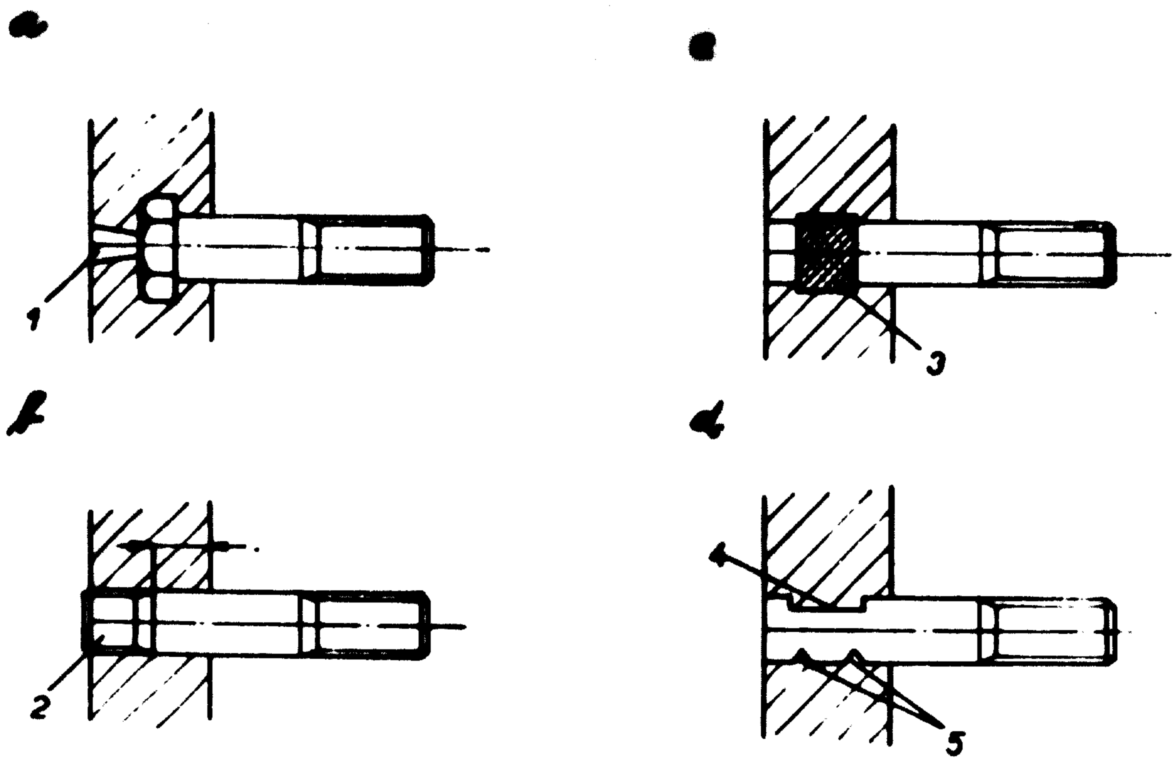
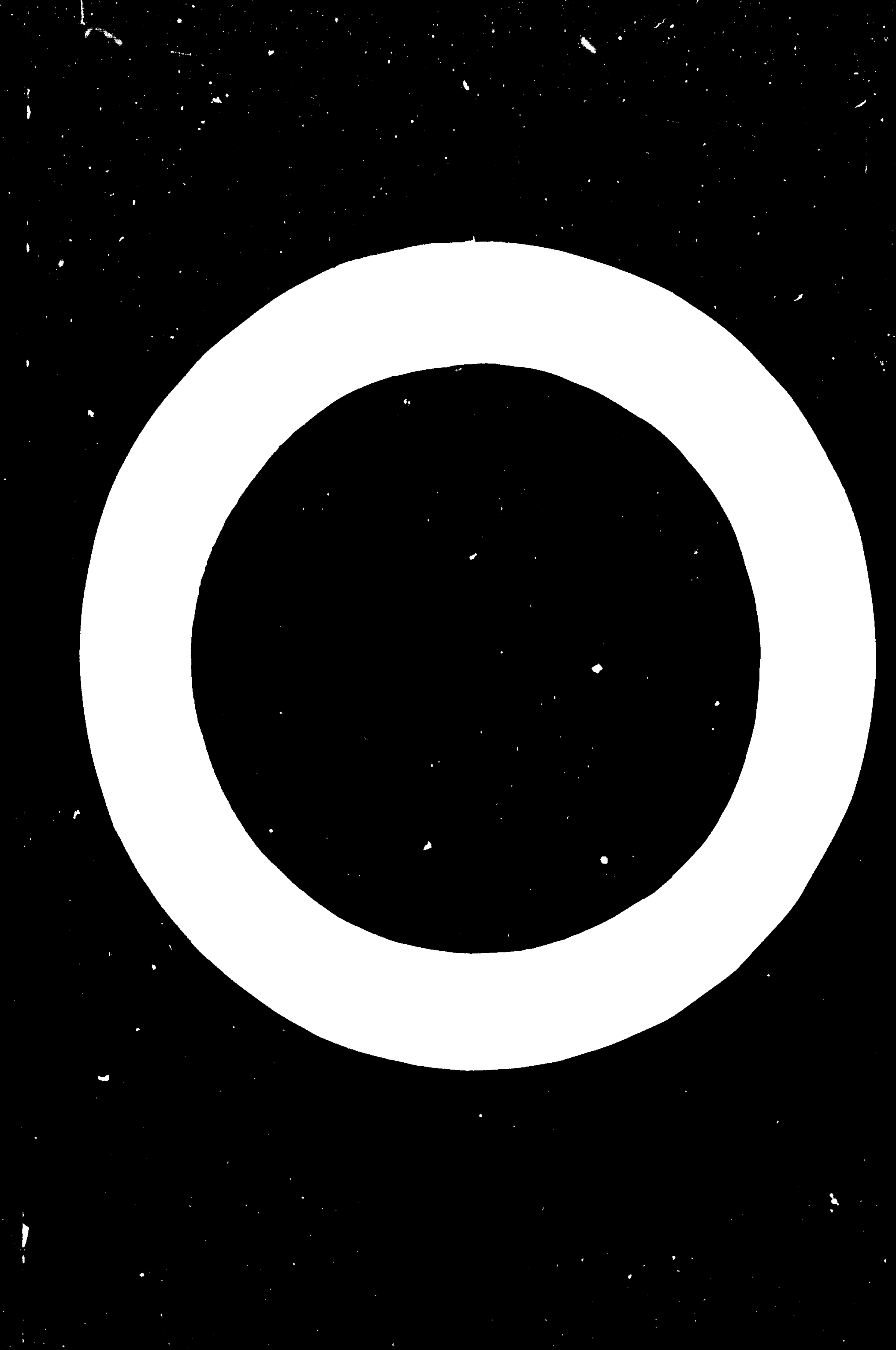


Fig. 28



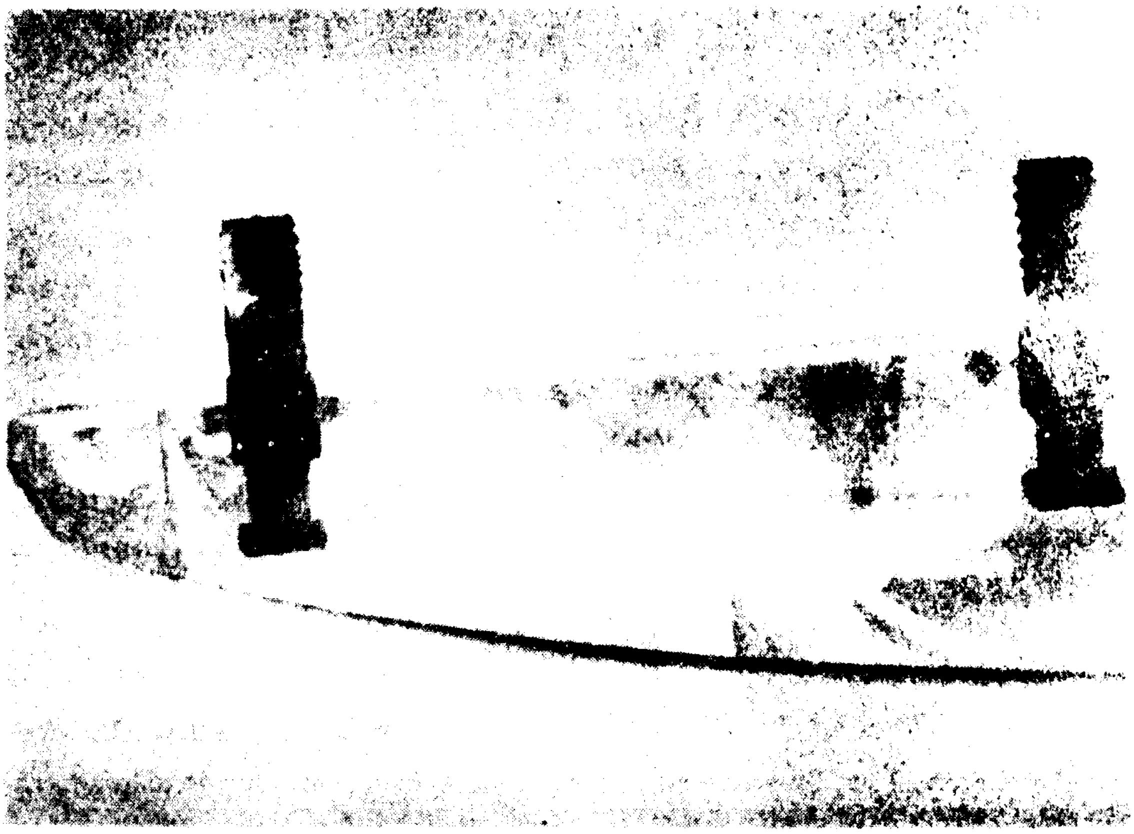


Fig. 29

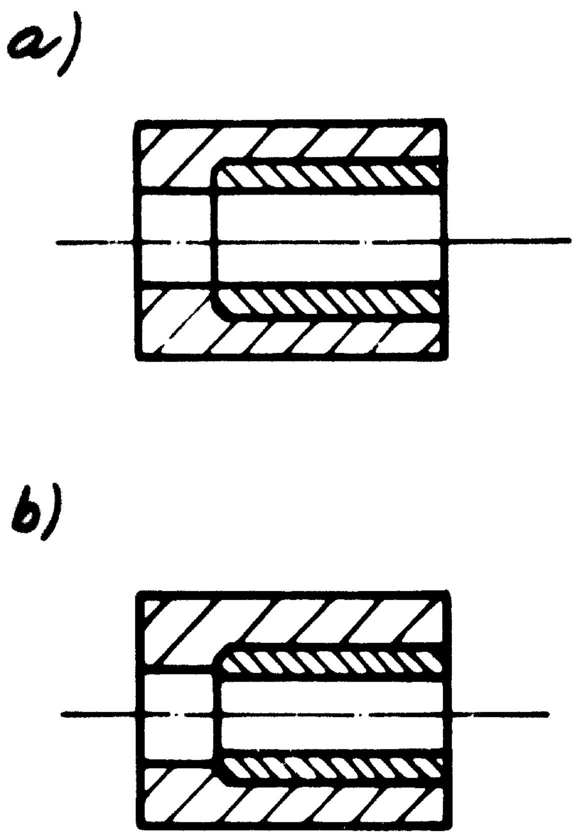
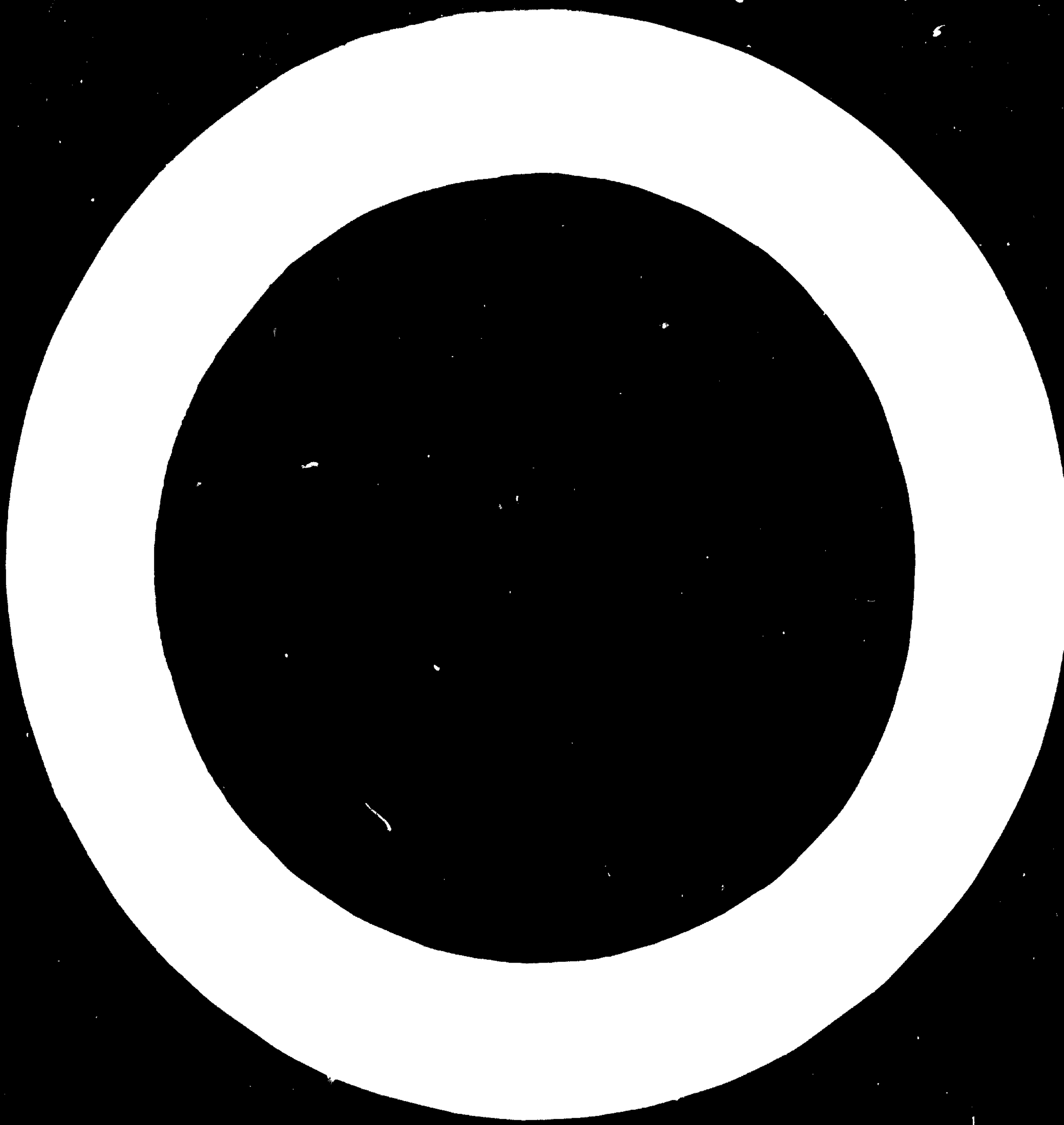


Fig. 30



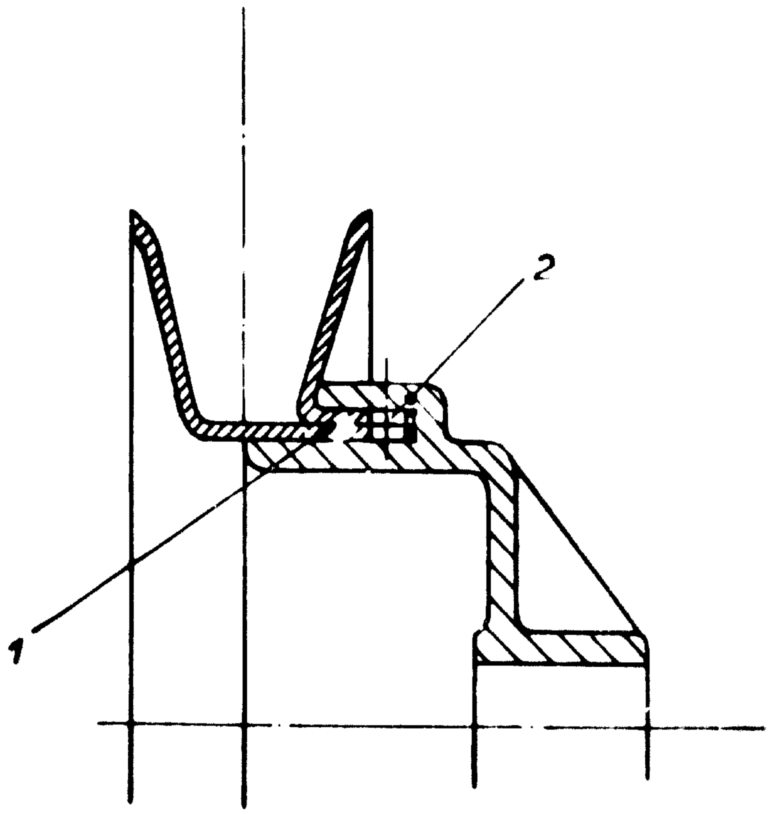


Fig. 31

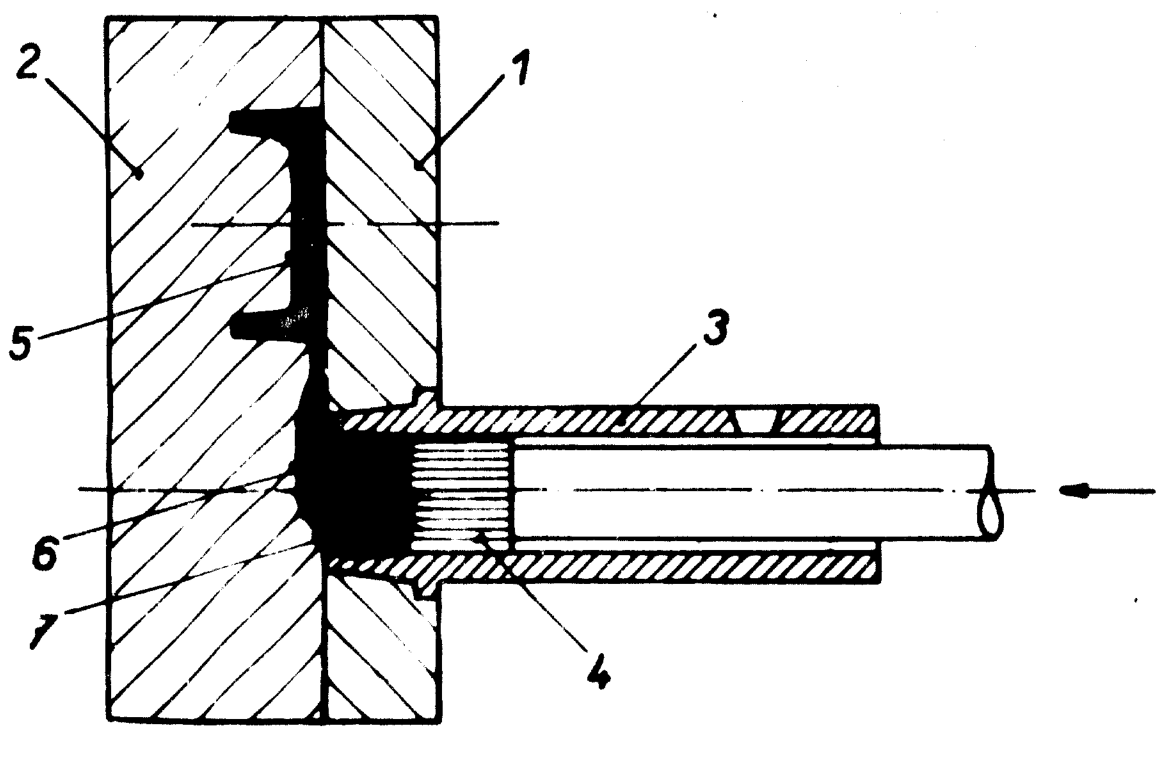


Fig. 32

Fig. 33

27. I. 72