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D04524

United Nations Industrial Development Organization

Distribution LIMITED

ID/WG.137/49
18 September 1972

Original: ENGLISH

Symposium on the Development of the Plastics Fabrication Industry in Latin America

Bogotá, Colombia, 20 November - 1 December 1972

AUTOMATION IN THE SPRAY-UP PROCESS FOR FIBRE GLASS REINFORCED POLYESTER RESINS[1]

by

J.Coudenhove-Kalergi

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Vienna Austria

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SUMMARY

AUTOMATION IN THE SPRAY-UP PROCESS FOR FIBRE GLASS REINFORCED POLYESTER RESINS [1]

by

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Vienna Austria

1. Introduction

Simultanous deposition of polyester resin and chopped glass fibres has become a well known method for the production of GRP parts. Several systems of spray deposition are known and will be considered. The use of spray-up equipment, however, still has remained at a fairly low level when compared with the oldest and most simple laminating technique, the hand-lay-up or bucket-and-brush method. As the GRP industry in most countries is shifting from small operators to larger industries, the search for automated producing methods becomes more and more intense.

2. Systems of Spray-up:

In order to fully understand the possibilities of automated spray-up we shall first take a look at the existing spray-up twin pot system (low pressure), one-component-system with catalyst injection and one-component catalyst injection system with coupled resin-catalyst pump.

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id.72-6184

3. Rotation Spray Casting:

The equipment basically consists of a rotating mould into which the resin-glass-laminate is sprayed. The resin-glass depositor is a very much enlarged version of the manually operated gun. It is mounted on a hydraulic ram and deposits the material into the rotating mould. An isophthalic gel-coat is deposited first, followed by a GRP laminate and finally by an isophthalic air curing top coat to give a smooth inner surface.

4. Spray Casting versus Winding:

Up to now, the ordinary winding and filament winding process was the only automated technique available for the production of cylindrical shapes. But for many purposes where laminate is subjected to stresses in more than one direction the spray casting technique with its fibres oriented at random has its definite advantages.

5. Spray Winding:

A new method using automated spray-up, i.e. the simultaneous deposition of liquid polyester resin and chopped glass fibre, for the production of GRP cylinders ranging in diameters from 400 to 4000mm is described. Along with the spray-up laminate continuous roving is applied. A wide range of mechanical properties may be obtained by varying the proportion of sprayed and mould glass reinforcement.

6. Hole-injection Process:

The process is performed by filling the opened two-part mould with dry reinforcing material such as glass fibre. After closing the pre-catalyzed and pre-accelerated resin is injected by the Poly-injector. One or both inner surfaces of the mould are covered by a gelcoat. After curing the mould is opened and the moulded part removed.

The arrival of such methods and equipment could vastly stimulate industry's interest in GRP as a construction material. Coudenhove Kunststoffmaschinen would certainly welcome the chance to collaborate with raw material manufacturers as well as potential GRP processors in search of new methods and new equipment to convert GRP processing from a handicraft into an industry.

1. Introduction.

Simultaneous depostion of polyester resin and chopped glass fibres has become a well known method for the production of GRP parts. Several systems of spray deposition are known and will be dealt with later in this paper. The use of spray-up-equipment, however, still has remained at a fairly low level when compared with the oldest and most simple laminating technique, the hand-lay-up or bucket-and-brush method. As the GRP industry in most countries is shifting from small operators to larger industries, the search for automated production methods becomes more and more intense. Hot and cold pressed moulding, winding and filament winding, automated sheet moulding etc. are rapidly becoming accepted. However, the above named techniques can be used only for a limited number of applications because of high cost of equipment and moulds. Limited production runs and sheer size of the article to be manufactured. This means that reinforced plastics are often excluded as a construction material by potential manufacturers not bacause of the quality of the material but for lack of production techniques

While the spray-up technique offers some tremendous advantage over the old hand-lay-up method, namely, fast application of fibre and roving, economical raw materials (there is a considerable price difference between roving and chopped strand mat), and easy application, is has two major draw-blacks: a) difficulty in handling existing equipment and b) high dependence on the operators skill.

With the new system of spray-up, utilising catalyst injection and combined resin-catalyst pumps, the first disadvantage has been considerably reduced. We will discuss this system later on. The skill of the operator, however, is still a major problem. While it does not take too great a skill to learn how to spray uniformly, operators in this field are very much sought after and fluctuation of such personnel in many countries is high. The trend for automating the spray-up process therefore is quite evident. This paper will deal with some aspects of automatisation, partly fully realized and partly in projection stage.

2. System of Spray-up.

In order to fully understand the possibilities of automated spray-up we shall first take a look at the existing spray-up systems:

a) The twin pot system (low pressure):

This system is the oldest and most commonly used way of spraying chopped fibreglass and polyester resin. The two resin componente, polyester with catalyst (generally benzoyle peroxide) and polyester with accelerator (dimethyl aniline) are stored in two separete pressure pots. The components are fed through hoses to a twin nozzle spray gun. The two jets of catalysed and accelerated resin are mixed in mid-air. At the same time a pneumetically driven cutter chops the roving into short lengths and deposite them on the mould along with the resin. The system is fairly simple and ie utilised frequently throughout the world.

Some of the draw-backs of this system ere: Limited potlife of the catalyst-resin component. This means that containers, hoses and guns have to be cleaned very frequently. Resin systems requiring MEK peroxide and cobalt accelerator cannot be used because of the extremely short pot-life of the MEK. Pressure pote have to be refilled periodically, making an automated process impossible. Capacity of such systems are generally small and therefore insufficient for rapid mass production.

b) The one-component eystem with catalyet injection:

One-component, or catalyst injection eystems work on a different besis: Preeccelerated resin ie pumped from an open drum to the spray gun where it is mixed with the etraight catalyat. The mixture takes place either inside a mixing chamber or outside of the mixing chamber in mid-air. The cetalyet is generally stored in e pressure pot and atomized prior to intruduction of the gun. A flow meter ie coupled with the catalyet syatem and allows for metering of the cetalyst.

c) The one-component catalyst injection system with coupled resin-catalyst pump

A new variety of this system is the socalled catalyst injection system with coupled catalyst and resin pumps. All equipment described in this paper has based on this system. Preaccelerated resin with an almost unlimited pot-life is pumped from the drum by means of a pneumatic 4:1 ratio pump and conducted to the resin despensing system. Coupled to the pneumatic pump is a catalyst pump which is agitated by the resin pump. The resin-catalyst ratio can be preset on a scale ranging from 0,5 to 7 % catalyst in relation to the pumped resin. The system works independent of viscosity of the two pumped media. One stroke of the resin pump equals one stroke of the catalyst pump. The catalyst is then pumped to the resin dispensing system. A flow indicator is built into the line and is coupled with a photo-electric cell. This in turn is connected with an acoustic warning signal which is sounded when flow of the catalyst has stopped. The resin dispensing system consists of two separate spray-heads which incorporate mixing chambers. Catalyst and resin are conducted to the mixing chambers separately and the components are intimately mixed before being sprayed. Two spray heads are used because of better wet-out of the chopped fibreglass which is ejected centrally and is seized and pre-wetted by the two resin jets from both sides. The fibreglass cutter is pneumatically operated. Various lengths of fibres can be produced. A solvent flushing system is incorporated. The mixing chambers are flushed by solvent after use of the equipment. No cleaning of lines or the rest of the equipment is necessary. The possibility of changing catalyst: resin ratio during operation of the equipment allows for optimal curing time of the laminates and thus rapid mould turnover. Special catalyst based on the acetyl aceton system are used. While the spray heads and cutters vary with the various models of equipment described in this paper, the system basically remains the same.

The spray-up process using a manually operated gun has found it's way into many industries. Containers of all sorts, car bodies, boats and furniture as well as vessels for the chemical industry, industrial flooring, swimming pools, prefabricated houses, and the like are to-day being manufactured by spray-up. Some excellent quality products are being made this way.

However, the consistent quality will depend to some extent on a good operator. The question we and probably all other manufacturers of spray-equipment are constantly being asked is: how can we be sure that we are getting a completely uniform laminate? Since there is no answer to this question except "Get a good operator", it was only too natural that we were beginning to ask ourselves how we could automate the equipment. This, of course, would apply only to cases where large runs of the same article could be made.

3. Rotation Spray Casting.

We received our first challenge some years ago when we were collaborating with an Austrian firm interested in producing agricultural silos for green fodder. This firm had long been aware of the qualities and stability of GRP for such silos. There are a number of firms on the continent, specializing in making GRP silos, using the winding technique, the hand lay-up technique and the manual spray-up technique. The plans of the Austrian firm, however, were such that large quantities of silos were envisaged and a special factory was to be set up expressly for this purpose. We were commissioned to develop a machine for the most economical production of such silos and it was decided that rotation spray-up would be the ideal answer.

The equipment we set out to build, basically consists of a rotating mould into which the resin-glass-laminate is sprayed. The resin-glass depositor is a very much enlarged version of the manually operated gun. It is mounted on a hydraulic ram and deposits the material into the rotating mould. The moulds measure 3,5 and 3 m respectively in inside diameter and have a length of 3 m. An isophthalic gelcoat is deposited first, followed by a GRP laminate varying in thickness from 6-7 mm. Finally an isophthalic air curing top coat is deposited into the mould again to give a smooth inner surface. Special auxiliary rollers are mounted to the ram in order to obtain a smooth and airfree laminate. A special venturi system in the cutter head allows for orientation of the fibres. In this way the mechanical properties of the laminate can be affected considerably. The sprayhead travels back and forth and deposits the material in several layers. Centrifugal force forces the material against the mould and keeps it from falling off. After the laminate has been cured the ring is taken out of the mould by a special method. The rings are then joined together in a very ingenious and quick manner. A top is then placed in the silo and the various openings are cut out. The hatch doors are then fitted in. It has to be realized that this was the first machine of this kind built by us and a great amount of experience has been gained in the course of setting it up. Those of you who are familiar with development work can realize the many difficulties and set-backs which had to be endured until the first silo came out impeccably. At this moment some 200 silos have been produced and set up. The Austrians have approached the whole project in a very serious and scientific way, have increased production constantly and have added some very important aspects to RP silos construction.

The tops of the silos mentioned above are manufactured on rotating moulds, using a manually operated catalyst injection equipment. It is planned to automate the rollings system too by using spring loaded special rollers.

The silos produced by the Austrian firm have been an excellent success on the market. The spray casting technique allowed the manufacturers to produce these silos at a price considerably below the GRP silos made by other firms with other techniques. This [illegible], farmers buying these silos also become eligible for government subsidies reducing the purchasing price for the buyer still further. Silos in sizes ranging from 60 to 96 m^3 are currently being produced.

4. Spray Casting versus Winding.

The spray-casting process as illustrated in the case history of the Austrian silos above shows some promising aspects for the future. Up to now, the ordinary winding and filament winding process was the only automated technique available for the production of cylindrical shapes. Originating in the military and aerospace industry the filament winding technology has been translated to many civilian goods such as pipes, chemical tanks, pressure vessels etc. While in a great many cases the winding process can never be replaced by the spray-casting method, it is believed that in some instances the latter process has its advantages.

A case in point is the spray-cast silo. For many purposes where a laminate is subjected to stresses in more than one direction the spray casting technique with its fibres oriented at random has its definite advantages. Mechanical strength of such a sprayed laminate is more or less the same in each direction as compared to the normally wound or filament wound structure. The silos are large cylinders which for technical reasons have to be supplied with many hatches in order to allow the emptying of the silo. These openings would naturally cause some serious weak spots in an ordinarily wound silo. In the case of a filament wound structure where roving are layed up in an axial direction as well the costs would become prohibitive. For this purpose the automatically spraycast product is very well suitable. As a rule of thumb one can say that an ordinarily wound vessel has seven times the mechanical strength in radial direction as the sprayed laminate. On the other hand in the axial direction the ratio is just the opposite, in other words the sprayed tank is seven times as strong as the wound tank, (using lathe type winding equipment). Naturally the wall thickness of a spray-cast tank will have to be higher. In the case of the silos these range between 6 and 7 mm. The advantage of this laminate lies in the fact that it can, with the above equipment, be accurately controlled. The random pattern of the fibres in the laminate is in this case a great advantage. Dr.Kurt Moser, Professor in Innsbruck and consultant , who probably has spent as much time as anybody in evaluating automated spray casting, calls this method "controlled disorder" referring to the random pattern of the fibres. The cutting mechanism of the equipment allows for a partial fibre orientation which leads to a 20 % increase of the laminate strength in radial direction. It can be said that in those cases where a structure is subjected to stresses in more than one direction the use of spray cast laminates should be examined. The silos currently used have a glass percentage of 33 % although a glass content of 40 % can be achieved. The cost of raw material has to be born in mind as this will very strongly affect the price of the end product. Glass roving to-day costs more than twice that of resin and as it has been found that satisfactory results were achieved with the 33 % glass content it was not found necessary to increase the proportion. Using the above ratio of 2:1 the end product naturally becomes considerably more economic than wound structures with a glass percentage of 60 % and over.

5. Spray Winding.

This paper will describe a new method using automated spray-up, - i.e. the simultaneous deposition of liquid Polyester resin and chopped glass fibre, for the production of GRP cylinder ranging in diameter from 400 mm to 4000 mm. Along with the spray-up laminate continous roving is applied. A wide range of mechanical properties may be obtained by varying the proportion of sprayed and wound glass reinforcement.

Collapsible mandrels made of metal or - for the larger diameters fibreglass are used. The length of the mandrels range from five up to twelve meters.

Some of the advantages claimed for the system are:

1) Laminate properties. A wide range of mechanical properties are obtainable in the finished laminate. The random distribution of the chopped fibres with a relatively high resin proportion results in a heavy laminate with uniform mechanical properties. This is of special value in those cases where the laminate is mainly subjected to external stresses rather than inside pressure. (Sewage pipes, storage tanks, underground tanks, etc.).

2) Flexibility of the system. Practically no down-time is required to change over from one diameter to another; a variety of different diameter pipes or tanks may be produced consecutively with hardly any change-over time.

3) Rapid production. One of the units currently in operation produces about 100 m of pipe per day (400 to 1000 mm in side diameter) per 8-hour shift. This rate can still be increased by adding extra mandrels.

The above system is currently being used in different countries for the production of tanks for the chemical and food industry as well as for sewege pipes and water pipes in the Austrian Alps. In the latter case, these pipes have successfully replaced Epoxy-lined steel pipes. Encased in concrete the GRP pipes have been able to withstand internal pressures up to 20 kg per sq. cm. (290 p.s.i.).

Development of the spray winding process was started in conjunction with an Austrian corporation in early 1970. A normal, hand-operated Polyspray fibre-resin spray-up equipment was hooked up to a home-made filament winding machine. Tests were so encouraging that the new equipment was built and put in operation in 1970. Since then the equipment has undergone important changes and improvements. It should be stressed that aside from the equipment itself the choice of resin and glass reinforcement were of considerable importance.

In the spray-winding process, chopped glass- fibre rovings and liquid catalysed accelerated resins are deposited onto a rotating mandrel turning clockwise from the spray-up equipment. The spray laminate hits the rotating mould vertically. A limited number of continuous rovings is simultaneously wound onto the rotating mandrel serving three purposes.

1) Keeping the sprayed roving from falling off.

2) Adding additional strength to the cylindrical structure.

3) Partly consolidating the laminate.

A pneumatically operated pressurized roller fully consolidates the laminate on the "north-pole" of the mandrel. The spray equipment is mounted on a trolley which also incorporates the entire equipment and which moves parallel to the rotating mould. The spray-up winding process may be repeated until the required wall thickness hass been achieved.

Mandrels are made in length of between 5 m and 12 m. The material is steel for the smaller diameters (100 mm to 800 mm) and GRP or fabricated sheet polypropylene for the larger diameters. The mandrels incorporate a pneumatically operated device for reducing the diameter prior to stripping off the finished cylinder. All mandrels can be easily taken out of the two sockets by means of an overhead crane. The mandrels are mounted over a deep sand-filled pit which forms a sort of mould. The turning speed of the mandrel relative to their diameter and the planned wall thickness to be applied in a single layer is, of course, of great importance. Tolerances of ± 0.25 mm currently can be obtained in the wall thickness of a cylinder. The mandrels are first given a layer of stripped cellophane followed by a layer of clear resin. This may be done on the rotating mandrel itself as in the case of large tanks.

In the case of pipes where rapid production is of essence, this operation is carried out on another site to save time.

The trolley which moves parallel to the mould on rails is driven by a gearless motor incorporated in the base of the trolley. A heated resin tank is mounted on the trolley. This tank has a minimum and maximum fluid level control system which in turn agitates a transfer-pump situated in the central resin tank some 15 m from the equipment. Thus, the small resin tank on the trolley is constantly kept full. The central resin tank, incidentally, is also pre-heated to a somewhat lower temperature.

A pneumatic piston pump designed and built by us for this purpose, pumps the preheated resin to the two resin spray heads. Coupled with the resin pump and agitated by it is a small stainless-steel-Teflon pump for the catalyst which is stored on the trolly in its original polythene container. The catalyst ratio may be set by means of a small handwheel mounted on the catalyst pump from 0.5 percent to 5 percent (in relation to the resin quantity). Thus, changes in the ambient temperature in the workshops may be corrected by altering the catalyst proportion to obtain uniform curing cycles. Easily legible charts have been prepared to instruct the operator. Special catalyst systems (mostly on the basis of acetyl acetone) are being used to obtain rapid curing cycles. The metered catalyst is mixed with the pre-accelerated resin in the two sprayheads. (two sprayhead are used, as in other Poly-spray equipment, in order to obtain improved wet out of the centrally ejected glass fibres.

The fibre cutter is pneumatically operated and allows for a rapid change of fibre lengths. Also mounted on the trolley is the central control cabinet and the creels for the winding roving.

After the mandrel which has already been coated with cellophane and resin, is lowered into position by the overhead crane, a resin-rich fibre-resin spray layer applied. Prior to this, a layer of glass or synthetic fibre veil may be incorporated as in the case of chemical tanks.

The laminate is subsequently built up in different layers. The equipment can spray continuously on both back and forth movements along the rotating mandrel. The equipment provides for uniform wall thickness even in the end zone where the trolley changes direction.

After the required wall thickness has been achieved, the roller mounted on the pneumatic device is exchanged for a coil of cellophane strip which is applied on the wet laminate in order to give a smooth outside surface. The mandrel is then hoisted from its base by means of the overhead crane and lowered into a large pit situated behind the equipment which houses a large number of mandrels of different diameters. These are kept in continuous rotation. The hot air which is blown into this pit, speeds up the cure of the finished GRP cylinders and at the same time preheats the stripped mandrels. At the present time only one mandrel with drive is being used. However, for future projects where a high output is required, two mandrels may be placed alongside each other. Thus, the equipment, with a doublelength set of rails may proceed to the next prepared mandrel immediately after finishing with the first one. Stripping of the finished cylinders takes place after about thirty minutes. In the case of tanks for the food industry, the vessels are post-cured afterwards for several hours with steam to remove the last traces of Styrene odour. The tank bottoms are being produced in the spray-up process and are bonded to the cylinders.

Water pipes.

An Austrian Power Company , after extended tests, has installed GRP pipes in their hydro-electric projects in the Austrian Alps. The pipe with inside diameters ranging from 400 to 1000 mm, is used to carry water to the artificial lakes feeding hydro-electric stations. Up to now, epoxy coated steel pipe was used for this purpose. The GRP pipe which is bought and installed at about half the cost of the formerly used steel pipe does not need any maintenance, whereas the steel pipe had to be relined with epoxy resin about every ten years. With pipes under 650 mm in diameter, relining was impossible as no man could get into the pipes to sandblast and reline the inside surface of the pipe.

Joining of the lengths of pipe is being carried out on site by hand using impregnated strips of glass fibre mat or cloth. Special contraptions have been devised to facilitate this procedure. Handling, transporting and joining the GRP pipes, of course, entail additional advantages as compared to the heavy steel pipes, which had to be welded on the spot in the often very rugged and mountainous areas.

The pipes are either buried in a sand bed or else concrete is poured around them. The latter method is used where heavy external stresses are to be expected. GRP with an outside casting of concrete will withstand high internal pressures and some of the pipes are intended for inside pressures up to 20 kg/cm^2 atmospheres. More than 5 km of pipe have been laid so far in the Heiligenblut area with an even larger stretch to follow this year.

On this project, a variety of different diameters are being used depending on the quantity of water to be carried in a particular stretch. The flexibility of the equipment, allowing for rapid changeover from one diameter to another without any down-time is a major advantage here. It would not be possible to carry out these rapid changeovers on an ordinary filament winding machine. Furthermore, the laminate produced with this system is much better suited to carry the high external stresses than would be the case with an ordinary filament wound laminate.

An additional advantage rests in the fact that pipes of different diameter can be slid inside one another so save space.

<u>Adapting existing filament winding equipment</u>.

To prove our point regarding the advantages of sprayed laminates in underground oil tanks, we would like to cite the example of the largest manufacturer of such tanks in the United States. There, so we are infored, the tanks are being produced in a similar system with the major part of the glass reinforcement being applied by spray-up.

Finally it should be mentioned that existing filament winding equipment may be adapted with some of the equipment mentioned above. One very useful device is the metering system for resin and catalyst. Such a unit, using the combined resin catalyst pumps and a mixing and pouring head incorporating a pneumatic stirrer has been successfully fitted to a considerable number of filament winding machines. Pre accelerated resin and catalyst are pumped from their original drums and conducted to the mixing and pouring head by means of flexible hoses. The mixing and pouring head is mounted above the resin bath through which the continuous rovings pass. The resin bath is also fitted with a maximum-minimum level control coupled to the pump system. In this way, a minimum quantity of relatively highly catalysed resin may be used in the trough.

A flushing device is also incorporated in the mixing head.

The pneumatically operated cutter as installed in our spray winding equipment, can also be incorporated in an ordinary filament winding equipment. This applies in the cases where the mandrel rotates counterclockwise and the saturated rovings are wound on to the mandrel on the underside. The cutter is mounted over the impregnated band of rovings and deposits the chopped fibres vertically downwards onto the surface of the impregnated roving band just before this is being wound upon the mandrel. The resin incorporated in the continuous roving is sufficient to saturate the dry chopped fibres.

6. Hole-Injection Process.

The success of spray-up moulding process during the last years was caused by the improvement of the machines. Nevertheless many GRP producers could not make up their mind to use spray-up moulding machines because of the dependence on skilled personnel. Particular in highly industrialized countries with a remarkable lack of man power it becomes more and more difficult to find skilled personnel.

There the hole-injection process seems to offer significant advantages:

The process is not new and it is well known by the designation "injection process". During the fifties it was known as MARCO process, followed by the [illegible] process. Some years ago, the process was recovered by a German machine producer. Recently the process was taken up also in England. But no success was reached which could be expressed by the statistics of the countries using that processing technique. Consequently, a breakthrough by the new COUDENHOVE equipment and the necessary know how seems to be rather possible.

The process is performed by filling the opened two part mould with dry reinforcing material such as glass fibre. After closing the precathalized and preaccelerated resin is injected by the Poly-injector.

One or both internal surfaces of the mould are covered by a gel coat. After curing the mould is opened and the moulded part is removed.

The process has the following advantages:

1) Uniform wall thicknesses of all parts whereby parts with different wall profiles are produced by additional lay-up of reinforcing material.

2) Smooth surfaces on both sides using gel coat at one side or at two sides.

3) Cleanliness and absence of smell because operations are done in closed moulds.

4) Facilities for automation similar to the fabrication of expanded polyurethane parts.

Just now the process did not succed by the following reasons:

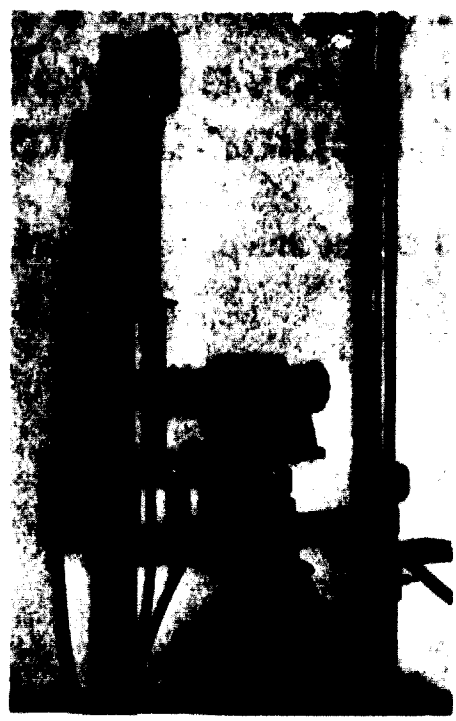
1) The twin pot system machines were not suitable for continous operations.

2) There was no knowledge of the mould making in the field of the hole-injection system. But mould design and mould making are the most important requirements for the efficient use of the process.

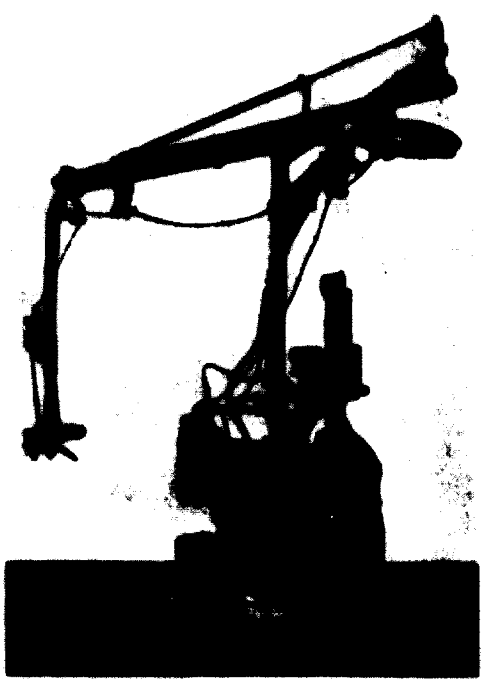
The two problems concerning spray-up machines, mould making and know how are solved by the latest development of COUDENHOVE hole-injection systems.

We are of the opinion that the arrival of such methods and equipment could vastly stimulate industry's interest in GRP as a construction material. Especially in the last two years or so there have been very strong tendencies on the part of large firms to investigate the possibilities of GRP. The majority of GRP processors are still on the small side but those firms who have seriously turned to automated processes such as press moulding, filament winding and prepreg processing already account for the bulk of raw material processed to-day. In Germany, for instance, a major resin supplier states that of the 500 or so domestic customers 20 individual firms make up for 80 % of resin turnover. We, as machinery manufacturers, would certainly welcome the chance to collaborate with raw material manufacturers as well as potential GRP processors in search of new methods and new equipment and help turning GRP processing from a handydraft into an industry.

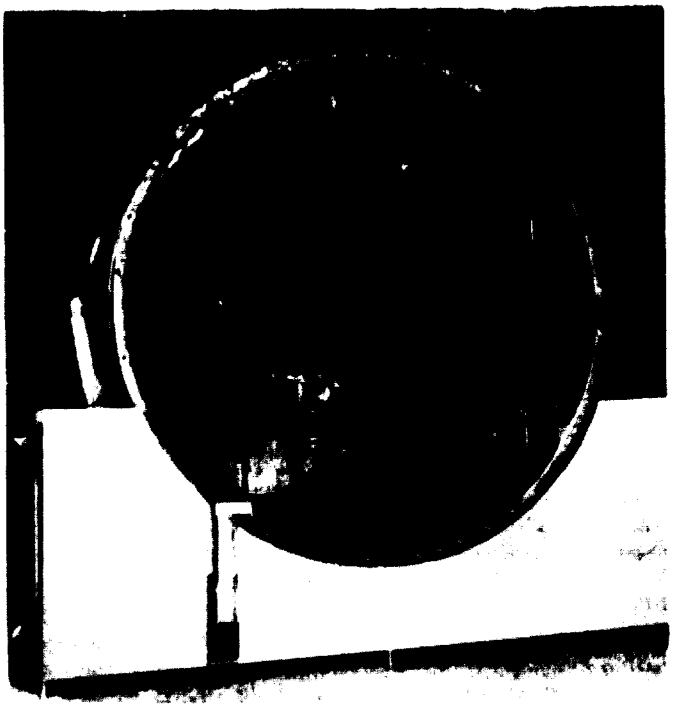
Resin/glass spray-up gun with two movable resin spray-heads



Combined resin/catalyst pump allowing for accurate setting of resin-catalyst ratio



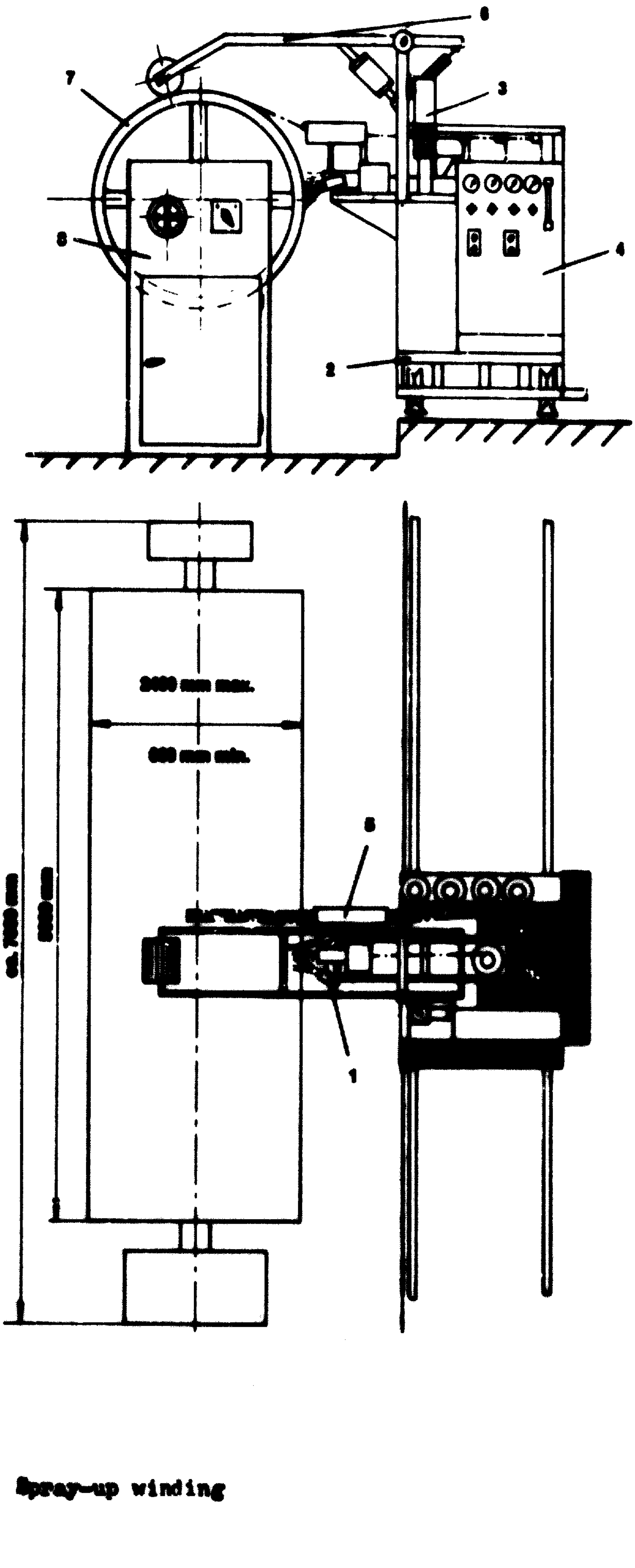
Polyspray M 10 resin fibre spray-up equipment



Rotation spray-up equipment. Rotating mould 3,5 m inside diameter

Resin/glass mixture is sprayed into a rotating mould

Agricultural silos, height 8,5 m made with rotation spray equipment



Spray-up winding

Manual spray-up of silo TOP using M30 equipment

Spray-up winding

Spray-up winding

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