4.1 The Parts to Understand

Although it is possible to produce rubber mouldings on virtually any machine with little knowledge of the equipment or technology, there are features of the equipment that need to be understood in terms of their function and interaction with the whole process. It is through this understanding that process analysis and prevention of failure is achieved, often referred to as failure mode effect and analysis (FMEA). It is a vital component in the selection of the injection moulding machine, and in the quality control of the process. It is not the intention here to catalogue all of the many machine configurations that are currently offered by machinery manufacturers, but to highlight the basic components that need to be understood and considered prior to the selection of the ‘perfect’ machine for the job.

The injection moulding machine consists of five basic parts:

- The pre-plasticising and injection unit
- Mould clamping mechanism and ancillaries
- Hydraulic power pack
- Heating/cooling system
- Control system

4.2 The Pre-plasticising and Injection Unit

Pre-plasticising is the term given to the conversion of uncured rubber to a hot, soft (relative), and homogeneous, plastic mass. This is achieved by the rotation of a metal screw within a heater-jacketed barrel. The relationship between the temperature of the pre-plasticised rubber and that of the jacketed barrel is dynamic, as the hot rubber exchanges frictional heat to the barrel walls or, depending on the heater setting, gains more heat. Rubber strip is fed to the throat, or inlet to the screw where it is sheared.
between the wall of the barrel and the screw flights. The plasticised rubber is forced by the screw past its tip and into the heat-jacketed injection barrel, where it is held pending the injection stroke. The plasticising action is controlled by:

- The design of the screw (length, depth of flight, screw pitch)
- The speed of rotation of the screw
- The gap between the screw and the containing wall
- The screw and barrel temperatures
- The ease with which the rubber can move from the screw into the injection barrel. Pressure applied against this movement of the rubber is known as ‘back-pressure’. Adjustment of the back pressure has a significant effect on the frictional heat developed and hence scorch and viscosity.
- The rubber compound(s) to be used.

The relationship between these variables is complex and needs to be fully understood through use of factorial experiment design for each type of machine used in the factory. The unit must allow the rubber to be processed uniformly without scorch. There must be a smooth pathway for the rubber, free from ‘dead zones’ where there is little or no rubber flow. Rubber that collects in these zones will soon cure to form hard ‘nibs’ that will grow in size until they re-enter the material flow, impede the injection, and produce moulding faults. This problem exists in many existing machines where the first rubber to pass into the injection barrel is the last to be injected, and may be partially retained for many cycles. The design of the injection unit is therefore crucial to the operation of the machine.

To avoid much of the problem, some machine manufacturers have reverted to the inline reciprocating screw design first used, in the 1970s and now called ‘first in, first out’ units, or ‘FIFO’. With this design, the screw is forced backwards by displacement with the rubber that it has plasticised. The plasticising barrel becomes the holding unit for the plasticised rubber. Injection is then achieved by hydraulically forcing the screw back into the barrel (see Figure 4.1).

The temperature of the screw cylinder, plunger, injection cylinder and nozzle need to be regulated. This is best achieved with jackets of oil circulating around each zone at precisely regulated temperatures. This same system must also be able to provide emergency cooling to prevent scorching of the rubber in the event of a prolonged delay in the moulding cycle. Some older machines are equipped with electric barrel
heaters, which need to be regularly monitored. For these machines the barrel will need to be emptied of rubber at any pause in the process and may even require to be cleaned with purging rubber (see Appendix 7 for examples of suitable purging compounds).

The way the rubber feeds into the screw has a significant influence on product quality. Designs that allow the rubber to be cut off in the feed zone (throat) by the screw flight cause extra work for the operator, and will give rise to an increase in screw speed as the ‘starved’ screw empties itself of rubber. This results in a rapid build-up of scorched material in the unit and, if it is not immediately detected and corrected, there will be insufficient rubber in the components (‘light parts’). A number of design features may be adopted to overcome rubber strip feed problems. Three solutions are regularly adopted, either alone or in combination:

- Motorised rollers to maintain positive contact between the rubber strip and the screw. Control measures ensure that the device is working only when there is a call for material feed.

- A localised increase of the distance between the screw and the barrel wall at the throat, allowing an initial contact between the screw-flight and the wide face of the strip.

- Teeth-like notches cut into the screw flights in the feed zone.

Figure 4.1 FIFO injection unit (courtesy of Klockner Desma)
The type of rubber to be used may require that special metals are selected for the construction of both screw and barrel. Halogen containing polymers can generate extremely corrosive breakdown products and their proposed use must certainly be discussed with the machinery manufacturer.

Some compounds contain fillers such as silica and silicates that have a significantly abrasive effect on the screw and barrel. Special steels may be appropriate to minimise wear, and additionally, the amount of wear should be measured and recorded on a regular basis (at least annually). Changes in machine performance can then be avoided by planned replacement of eroded machine parts. If wear goes unchecked then the performance of the injection machine will change and affect product quality. The first sign of this could be an onset of moulding rejects.

The final part of the unit is the nozzle. This part of the machine has been given the least attention by machinery manufacturers but is very important to efficient operation of the unit. The design of the nozzle and the control mechanism of the injection unit mechanism, affect the quality of the compound as it leaves the injection unit and is the final point of departure for the rubber from the injection unit. It channels the rubber directly into the mould through a hemispherical mating face to the top of the sprue bush in the mould and then leads to the centre of the runner system. Most machine manufacturers design the nozzle with a parallel bore at its exit. For minimum pressure drop through the nozzle it is desirable that the nozzle is made with a smooth conical path to its end (Figure 4.2). This channels the pressure to where it is required - in the mould! The mould design should always include a matching nozzle that has an exit diameter at the point of contact to that of the sprue bush. Designers often make the mistake of under sizing the nozzle and sprue bush in the belief that they are saving the company money by minimising the volume of compound used for each shot. Under sizing will lead to a reduction in the pressure available in the cavity and an overall increase in the time needed to fill the cavity.
4.3 The Press Unit

The press comprises a machine that will:

- Open the various sections of a mould,
- Allow the placement of inserts,
- Close the mould sections, and
- Close and securely clamp the mould sections together during the ensuing injection and curing cycle.

The selection of the press is directly related to the type of product and the size of mould to be used. The scale of everything fitted to the press is controlled by these factors. The choices to be made are as follows:

- Horizontal or vertical opening.
- Hydraulic or toggle closing, opening and clamping mechanism.
- Various ‘ejector’ systems to manipulate the mould.
- Mould loading devices for inserts.
- Component unloading tools.
- Access requirements for mould fitting and changing.
- Operator position and reach.
- Safety features.

These choices can only be made prior to purchase. They are of the utmost importance to ensure that the injection moulding machine will produce high quality products. The decision making process must also consider the effect each feature will have upon the cycle and the machine operator. The aim must be to ensure an operation that will be consistent and cause the minimum of stress to the operator.

Press manufacturers in Europe produce a wealth of different press configurations and will also produce presses to suit the needs of individual customers. However, it should be remembered that the press manufacturer is an expert in engineering but may not be an expert in all of the aspects of processing.
4.3.1 Horizontal or Vertical Opening?

Presses with horizontal openings have usually been designed for short cures and fast cycle times. They are useful for rubber products that do not require inserts. Although inserts may be positioned in the vertical open mould face, press operation movements will cause significant dislodgement, producing components without the required insert, ‘light’ parts, and mould damage.

Horizontal presses occupy greater floor space than their vertical counterparts but less headroom. The press shop layout and construction is therefore an important consideration. One great advantage of horizontal presses is the accessibility of the screw, barrel, and nozzle unit to the operator.

4.3.2 Hydraulic or Toggle Clamp?

Hydraulic mechanisms have proved the favoured means of press operation within the rubber industry for a number of reasons. Historically, before the advent of the injection process, rubber moulding was accomplished using compression or transfer techniques with hydraulically operated presses. These presses could be manufactured cheaply and run using water as the hydraulic fluid, with a simple accumulator system to develop the necessary pressure. The same water supply was used to raise the high steam pressure that was used to heat the platens. The operators required to set up these simple presses could be easily trained and needed no special engineering skills. The rubber industry was therefore conditioned to the use of hydraulic presses, well before the advent of injection moulding. In time the hydraulic systems were refined and changed to oil.

A toggle operated press is one where the opening and closure is effected by folding and straightening sets of hinged bars that connect the moving platen to the end frame of the machine. This type of mechanism can be made to move very fast, which will minimise the amount of time required to open and close the mould. The clamping force exerted comes from the elastic modulus of the steel tie bars that support and guide the moving platen and toggle mechanism, and join the fixed platen to the end frame of the machine. These bars are forced into tension as the toggle is straightened and locked into its fully extended position. The setting of these toggle mechanisms is critical if the correct clamping pressure is to be achieved. Over the years machine manufacturers have produced many variations in the toggle design to improve the ease of operation. Even allowing for such refinements, the purchaser of a toggle machine must examine the operation in detail and also consider the impact of wear on the closure mechanism.

In practice, many presses combine hydraulic and mechanical locking processes. High speed, low pressure, jack rams are used to effect a rapid movement to a point
just short of full closure. A mechanical lock is then swung into position between the moving platen and the main, high-pressure ram, which then applies the full clamping pressure. This system reduces the high pressure demands on the hydraulic system to a minimum [1].

4.4 Hydraulic Power

The modern press requires refined pressure control throughout the moulding cycle. The hydraulic system powers the jacking and clamping mechanisms and all the ancillary systems such as the screw and injector unit whilst, at the same time, powering the operation of the ejector bars. The design of the unit must be such that it can supply sufficient oil pressure to operate all the press functions that are likely to be required at the same time. Some systems are designed to deliver oil in a way that precludes concurrent operation. This results in significant waiting times in the moulding cycle whilst hydraulic pressure is built up.

4.4.1 Oil Cooling

The flow of oil through pumps, valves and pipes creates a great deal of heat. As the temperature of the oil rises there is a corresponding drop in viscosity. If the oil becomes too thin, damage can occur to the pumps and valves. As the viscosity decreases, the oil can escape past poorly made connections and will permeate rubber-bound sealing gaskets. It is therefore important that the cooling services to the press are properly maintained. Failure to look after this basic cooling need will lead to costly failure in the future. Cooling the oil will consume a great volume of mains water, and the cooling pipes become rapidly ‘furred’ or scaled if the water contains any calcium or magnesium salts. For presses in continuous operation it is necessary to provide a closed loop cooling system using a heat exchanger and de-ionised water. In winter the extracted heat can be used to help heat the factory.

4.4.2 Clean Oil

High-pressure hydraulic pumps contain components that are made to closely defined tolerances. For this reason it is very important that the oil that is used within the system is clean. Contamination of the oil, down to particles too small to be seen by the human eye, leads to erosive wear of the pump and a gradual loss of system pressure. It is well worth ensuring that oil maintenance is given a high priority and that sub-standard oils are not used.
4.5 Heating and Cooling

The temperature of the plasticising unit (comprising the screw, injection barrel and nozzle) is controlled by the use of jackets, through which a heating/cooling medium is circulated. The medium is either water or heat transfer oil. The choice between these two media is governed by the highest operating temperature of the unit. At temperatures below 95 °C water is satisfactory. Where operation is to be at or above 100 °C then oil is necessary. The purpose of the unit is to provide a consistently plasticised stock at uniform temperature, therefore, the temperature control unit must have the capacity to remove excess heat, and to provide a balance to heat lost after the plasticising action of the screw has stopped. The closer the temperature is kept to the set point, the better. An operating temperature fluctuation of greater than 3 °C should be regarded as less than satisfactory. On older presses the temperature control of the pre-plasticising unit is often separate from the main control unit. In such cases it may be prudent to apply regular, recorded checks to ensure that the temperature control is operating correctly.

The units are also designed to effect a rapid (or ‘crash’) cooling of the injection unit in the event of an un-programmed interruption in the operation of the cycle. The rapid cooling ensures that the rubber does not begin to cure in the injection unit before it can be safely removed or replaced with a purging compound.

Cold runner systems have a similar temperature control requirement to the plasticising and injection unit, since the cold runner acts as an extension to the nozzle, controlling the rubber temperature to preclude any build up of scorched material while it awaits injection into the mould.

4.5.1 Platen Heating

Press manufacturers have reacted to the need for improved temperature control of press platens. Electric heating elements are zoned with separate temperature controls applied to each zone. By this means it is possible to limit temperature gradients across the platen to ± 1 °C. The temperature gradients across the mould are less predictable and depend upon the mould geometry and construction, zone setting, and ambient conditions around the press. Temperature control of the platen depends on all of the elements within the platen being operational. If an element close to the controlling thermocouple becomes open circuit, the controlling sensor will call for additional power to the functioning heating elements to offset the temperature drop from the defunct element. This has the effect of creating hot spots, or temperature gradients in the platen and mould. Heating systems should therefore include self-diagnostic systems that will alert the user to any problems.
With the vertically mounted platens of horizontal presses there is an additional problem. Upon opening, strong thermal gradients are created vertically, producing a pronounced cooling effect at the lower part of the open mould faces. This can be counteracted by placing thermal barriers above the platens to prevent ingress of cold air, and by ensuring that the press is only open for a very short time. A sure sign that convectional cooling is occurring is the need to extend cure times to eliminate under-cure of components in the lower cavities of the mould.

### 4.5.2 Cavity Temperature

Close control of curing temperature can be accomplished by the use of individual heating and control units for each cavity. By this means it has been possible to obtain very consistent results from sample to sample and batch-to-batch. At the time of writing the author is not aware that this technique has been applied on a production basis.

Earlier it was stated that press manufacturers have made substantial improvements to the temperature control of platens. This work has to be extended to ensure that the moulds become integrated into the system. Some thermal control systems are available which allow such control, but cost is cited against their use to eliminate cavity-to-cavity variation. It is not logical to expect any system to maintain close temperature control over an area of half a square metre from one pair of thermocouples! Greater control will pay real dividends by allowing the technologist to optimise a cure time that is based on equal crosslink density rather than the cure time required for the coldest cavity.

### 4.6 Control Systems

Control systems have become an integral part of the injection moulding machine. The heart of the system is a processor unit (programmable logic controller) often called the PLC, which is pre-programmed with the basic operational commands that work the electro-mechanical part of the package. It is the PLC that provides the logic functions for auto- and semi-automatic operation, controlling the stop and start of pumps, adjusting pressures, reading micro-switch positions and all the other many functions of the machine. The user interface has a display screen and keypad to input the required operating parameters. Once satisfactory conditions are attained, the values of each setting can be stored as an integral computer file that can be recalled against a particular job number or description. It is essential that such stores are equipped with the means for data back-up, preferably automatically, for example through the company intranet.
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As quality systems demand greater process integrity, press shop managers will take advantage of remotely programmed presses that are set up from a central server unit. This also monitors press operation, tracking operator efficiency and providing the operators with guidance to improve their performance. The effective press shop manager must be aware of the monitoring functions of the machines in his charge, and ensure that they are utilised fully to give viable operation in both quality and cost effectiveness.

Reference