Portable force measurement device for preventive maintenance on injection molding machines

by Walter Vordermark

Injection molding machines can produce waste when both halves of the mold are not parallelly closed. Additionally, wear occurs on the mating surfaces. These problems can develop whenever the closing force distribution in the four tie-bars of the injection molding machine is uneven. These forces are measured with mobile strain measurement equipment and can be directly displayed in newtons when the diameter and modulus of elasticity of the tie-rods have been included in the calibration of the measurement chain. Uneven force distribution can be corrected by means of adjustments to the tie-rods. In this way damage to production equipment is effectively prevented by easily handled mobile measurement equipment.

Injection molding is a method for the mass production of plastic parts. Although plastics contain a high proportion of petrochemical raw materials they still qualify as energy-saving materials, because apart from the unavoidable expense of processing, their costs in association with transport are very low. The value of plastic parts is further strengthened when their energy-saving aspects are compared with those of the conventional means of transport. Since only five percent of the world oil production is used in producing polymers, it is easy to see that in contrast to such conventional metallic raw materials, the possibility of a future shortage is hardly likely.

Injection molded articles are often required to meet a great number of demands. Mechanical stiffness, corrosion resistance, specific thermal properties and resistance to fire are of primary importance. The manufacturers of motor vehicles require that the molded article be weather-resistant and light-fast as well as having a good appearance. The plastic parts of modern electrical household appliances (e.g. electric mixers, can openers, toasters, etc.) have to be nontracking and have exceptional dimensional stability as well as being resistant to moisture and water. Packaging for the food and pharmaceutical industries are subject to strict health or food and drug regulations.

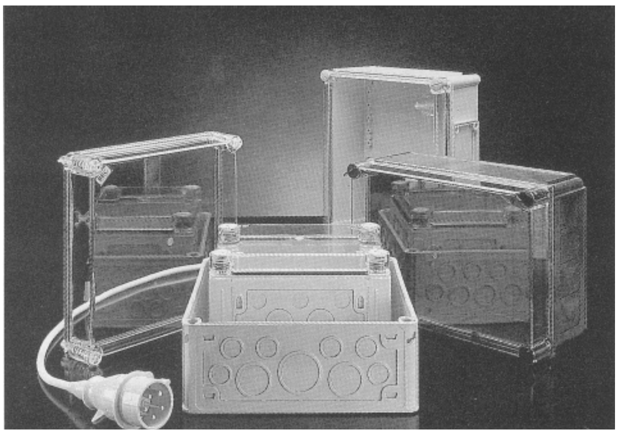

Fig. I: Electrical distribution boxes formed from injection-molded plastic

Due to the great versatility of injection molding, practically unlimited design innovations are possible. Articles are usually processed from thermoplastic polymers which are available in the form of granules, e.g. polycarbonates, polyamides, ABS or PVC polymers, as well as from thermoelastic polymers such as cellulose esters. In order to obtain specific properties, mixtures of these and other polymers are blended [1]. **Fig. 1** shows some typical electrical equipment boxes produced by injection molding.

Operating principle of the injection molding machine

The principle structure of an injection molding machine is shown in **Fig. 2**. An injection molding machine is a system which consists of several components, the most important of which are the heated plasticizing cylinder containing a reciprocating and rotating screw, a hydraulic injection piston, the two piece mold called the tool, and the associated platens and clamping devices. The closing and clamping equipment usually consists of a hydraulic clamping cylinder or alternatively consists of a mechanical-hydraulic toggle joint clamp. Universal machines are generally equipped with a chain driven mold height adjustment. The individual components are horizontally arranged on a common machine bed.

The polymer granules are fed from the hopper into the heated plasticizing cylinder and brought to the required injection temperature. The injection occurs when the hydraulic injection piston and cylinder are actuated and an axial movement is introduced to the screw. The molten polymer is forced into the mold cavity. The article then solidifies in the mold, during which time the screw remains in its foremost position and holds the shot of injected material under pressure. The screw is then retracted, allowing a new charge of polymer to be heated and plasticized. In order to eject the solidified article, the clamping cylinder is loosened, the platen and one mold half is drawn back. The mold is subsequently closed in preparation for the next cycle [2].

Force and pressure

When the term "injection molding" was being given to this manufacturing process for plastic articles, no reference was made to the terms that are important in the process, namely force, strain and pressure. Instead, the name was derived from the die casting machine [3] which employs a method similar to injection molding to produce articles from non-ferrous metals. During the injection cycle the two part mold is pressurized to a certain internal pressure. This pressure is obtained from the injection piston output power and is transmitted by means of the screw and the molten polymer mass to the mold. Previously, this characteristic quantity for the performance was simply quoted as the metering capacity of the plasticizing screw [4]; the injection pressure and clamping pressure, necessary to assure the proper formation of a molded article remained in the background. For the production of injection moldings of simple shape and specification, these factors were relatively insignificant. Nowadays, there is an increasing demand for articles with thin walls which require substantially higher pressure to produce. Higher mold and injection pressures increasingly stress the closing and clamping equipment.

The important parameters for injection molding are the internal mold pressure, product temperature, as well as the closing and clamping pressures. These values govern the shape and properties of the final article. The internal mold pressure is normally measured with pressure transducers. The pressure signals, along with the product and injection temperatures are used for the control of the injection molding machine. It is not intended to discuss this aspect of the process in this article.

The internal mold pressure produced during the injection cycle attempts to buckle or deform the two halves

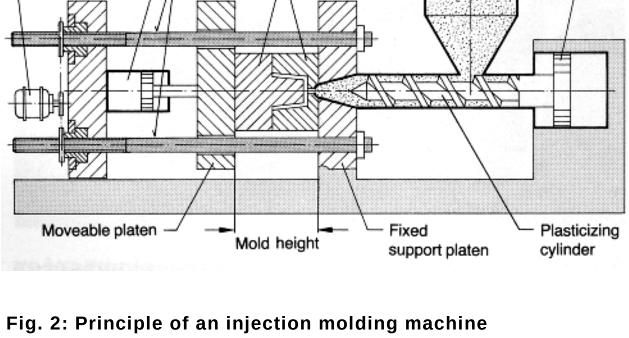

Fig. 2: Principle of an injection molding machine

of the mold. If successful the mold "breathes". Molten polymer then flows out between the buckled surf aces, and after solidification, forms unwanted flash on the molded article. This produces waste and rejects. A higher closing pressure must therefore be produced by the hydraulic clamping piston.

As shown in **Fig. 2**, the closing and clamping force is produced from a hydraulic clamping cylinder and transferred to the moveable part of the mold. The clamping cylinder and the stationary part of the mold each bear upon different support platens. These two support platens are connected by means of four tiebars that act as elastic columns which absorb the closing and clamping forces. At the same time they act as guide rods for the moveable platen which supports one half of the mold.

Problems for the operator

Essential for the rational operation of an injection molding machine is that only minimal amounts of waste and rejects be produced. Downtime caused by upsets, necessary repairs or preventive maintenance must be reduced to the absolute minimum. Waste and rejects can be produced when the two halves of the mold are not parallelly closed together due to uneven column force distribution. There are also design defects in the form of unwanted flash, material defects in the form of porosity and structural defects because the parts have warped and not kept their shape. At the same time tool and form wear occurs. The formation of burrs on the molds can damage the hardened surface layers. If the clamping force is distributed unevenly to the columns it is possible for individual columns to be overstrained and tear. Assuming that owing to an uneven distribution of the clamping force one column takes up only a small fraction of the total force then the other three columns could be heavily overloaded. It often happens that due to wear, the driven cogwheels on the motorized mold height adjustment slip. Consequently this slippage has a detrimental effect on the distribution of force in the columns.

Problems for the manufacturer

During quality assurance checks or acceptance tests under guarantee, the manufacturers of machines must show that the adjustment of the clamping forces is correct. In accordance with the guarantee conditions that are usual in this branch of industry, they must also provide a guarantee for a negotiated period of time. Repairs under guarantee are normally expensive. Should one of the columns fail, it has become common practice to change all four columns even when only the one is defective. Moreover, a diagnosis of this problem is difficult without a means of force measurement.

The use of portable measurement equipment for the determination of strain in the stressed columns of machines can be a valuable aid to manufacturers and operators alike, for it avoids the faults described and therefore reduces the problems associated with them.

Force measurement principle

The purpose of the measurement is to ascertain and compare the axial force in each of the four columns. The force is measured indirectly by means of the strain in the columns which is proportional to the force. HBM clamp-on strain transducers Type DD1 are placed on the columns and measure the surface strain with high

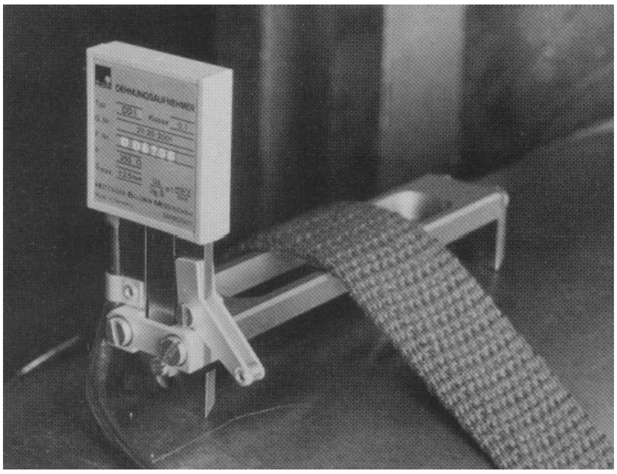

Fig. 3: Type DD1 strain transducer clamped to a injection molding machine for measurement of the column force

accuracy. **Fig. 3** shows one DD1 clamp-on strain transducer attached to a column. Over the years the Type DD1 strain transducer has proven itself to be extremely well suited for measurements in materials testing, as, for example, in the strain measurements during tensile tests.

Measuring strain with the DD1

The operating principle of the strain transducer DD1 is based on the movement of a sensing knife-edge which is transformed into an electrical signal proportional to the displacement. The moveable knife-edge of the DD1 transfers the surf ace strain of the specimen to a tongue which flexes by an appropriate amount. There is a full-bridge, compensated strain-gage circuit mounted on the tongue which produces an electrical signal proportional to its deflection. **Fig. 4** shows schematically the construction of the DD1 in the form of a clamp-on strain transducer.

For the measurement of strain, two clamp-on strain transducers are mounted opposite each other on each of the four columns. The attachment is accomplished by means of commercially available textile tensioning belts. This allows the placement of the transducers on columns of various diameters. **Fig. 5** shows the clampon strain transducers attached to the columns of an injection molding machine. The opposed pair-wise arrangement of the transducers was chosen to avoid the falsification of the force measurements due to possible bending of the columns. When the two transducers are connected in parallel, the measurement signal produced is the arithmetical average of the two individual signals. This eliminates the effect of any bending stresses which produce the same magnitude of strain at the two transducers but of opposite mathematical sign. Pairs of transducers are used to take measurements on all four columns.

The transducer pairs on the four columns produce one signal each. The four signals are fed to the manual measuring point selector UMK 10, which selects one

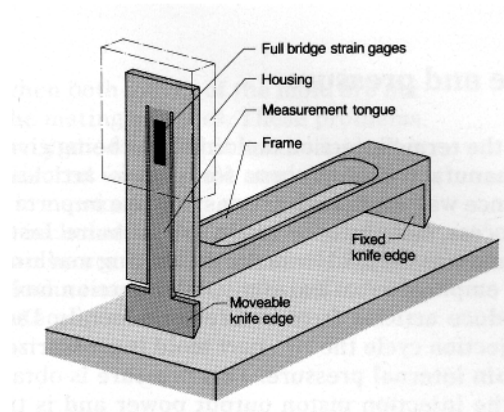

Fig. 4: Basis construction of the DD1 strain transducer

of the four input signals and then connect it to the input of the digital strain meter DMD 20A. **Fig. 6** shows schematically the measurement chain. The DMD 20A is a small, handy unit. It is therefore conventiently portable and well suited for the local amplification and display of the measured signals from strain gages. By proper adjustment of the digital display, the measurement signals which have been selected by the UMK 10 can be directly read out with the desired units. In this case the force acting in the column is displayed directly in Newtons. After the selection and comparison of all four measurement points, it can be determined if the columns are equally loaded. This is an essential check during the acceptance tests on new machines and can also be repeated regularly during normal service as a

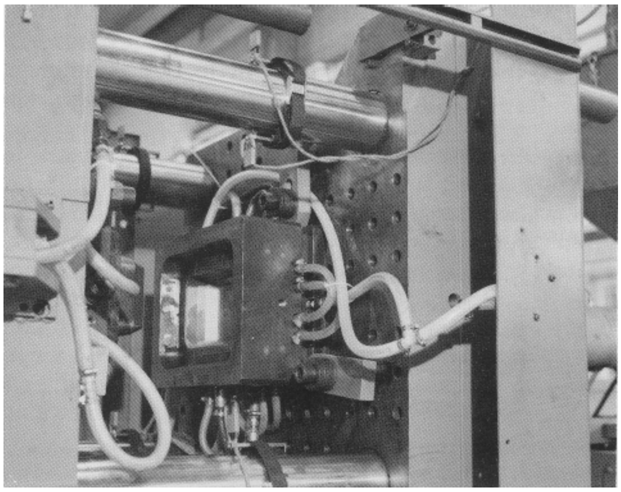

Fig. 5: Strain transducers clamped to the columns of an injection molding machine

preventive maintenance routine. The results of the measurements can be entered in the equipment maintenance records.

By switching the signal between the four columns, major discrepancies will easily be seen between the previously recorded and current values. This device will then show one column with a greatly reduced stress and correspondingly an increased stress in the other three. Thus, a cracked column, usually impossible to detect visually, is very easy to diagnose with the aid of this instrumentation.

Adjustment of the digital strain meter DMD 20A

On the front panel of the DMD 20A digital strain meter as shown in **Fig. 7** is a "k-factor" switch which allows the sensitivity of the instrument to be adjusted to the particular task in hand. The adjustment facility allows the correct numerical value of the column force to be displayed even though it is the strain that is being measured.

To obtain the proper setting of the k-factor, it has to be calculated with regards to the shaft diameter *d* and the modulus of elasticity *E*. The general relationship between force *F* and strain ε in the column is:

$$F = \varepsilon E A \qquad (1)$$

where A is the cross sectional area of the column. For example, with *d* equal to 60 mm (2.4 in) then A is 2827 mm^2 (4.38 in 2). With *E* equal to 206,000 N/mm^2 ($2.99 \cdot 10^7$ psi), then

$$F = \varepsilon \cdot 582.4 \cdot 10^6 \text{ N} = \varepsilon \cdot 130.9 \cdot 10^3 \text{ lbf} \qquad (2)$$

The next step is to consider the output signal of the DD1 clamp-on strain transducer. A 1 mm (39.4 mils) deflection of the measuring tongue produces an output

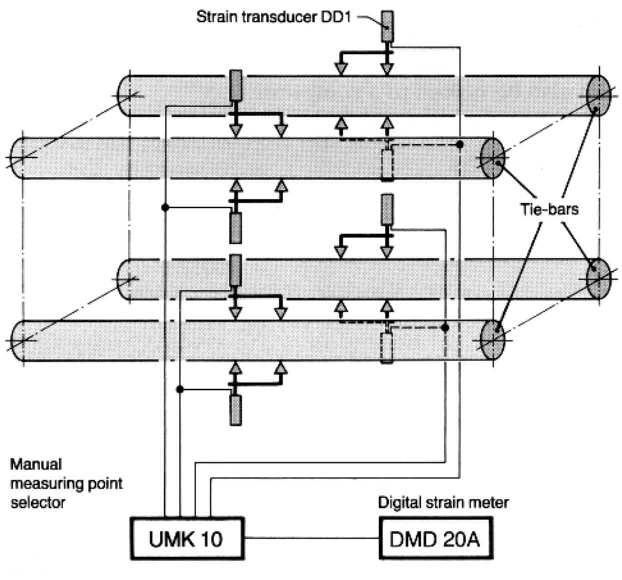

Fig. 6: Diagram of the instrumentation system with two strain transducers on each of the four machine columns

signal of 1 mV/V. With a nominal distance between the fixed and moving knife edges of 100 mm (3.94 in), this corresponds to a strain of $\varepsilon = 10{,}000 \cdot 10^{-6}$. If the DMD 20A has an input signal of 1 mV/V and the k-factor k_E, stands at 2.00, then the display shows a digital value of 2000. A change in the value of k_E changes the sensitivity of the DMD 20A. If k_E is changed to 1.00, then the sensitivity is doubled. In other words, 1 mV/V corresponds to 4000 digits.

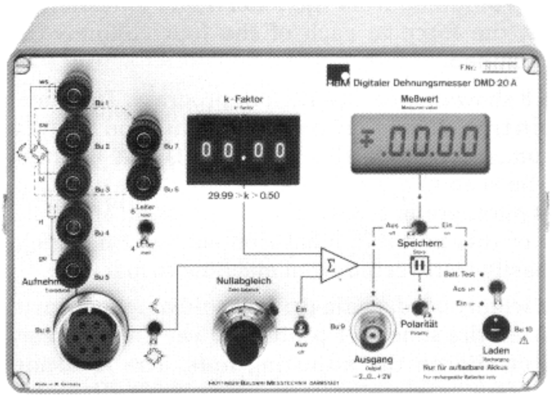

Fig. 7: Type DMD 20A digital strain meter with k-factor adjustment from 0.50 to 29.99

Since an input signal of 1 mV/V corresponds to a strain a of $10{,}000 \cdot 10^{-6}$ it follows from equation (2) that the force *F*, equivalent to this strain is 5824 kN ($1.309 \cdot 10^6$ lbf). The value of k_E is determined through the use of the simple equation

$$k_E = 4000 \, \frac{S_N}{D} \qquad (3)$$

where S_N is the nominal output signal of the DD1 (1 mV/V) and D is the expected display value (5824). Substituting into equation (3) gives

$$k_E = 0.69 \qquad (4)$$

The k-factor is then adjusted to 0.69*. By means of this adjustment it follows that for an input signal of 1 mV/V, the DMD 20A produces a display of 5824 digits (5824 kN). Therefore one digit corresponds to a force of 1 kN in the column.

The measurement procedure

If the knife-edges of the clamped-on transducer slip when the machine opens and closes, the cause is usually an excessively smooth surface on the columns. All oil must be cleaned from the surface which can then be slightly roughened with a fine emery cloth in the circumferential direction so that the knife-edges can grip properly. In other cases a thin film of adhesive helps.

***** To obtain a value in lbf the k-factor is adjusted to 3.06. Therefore a signal of 1 mV/V corresponds to 1309 digits (1309 10^3 lbf) and one digit corresponds to 1000 lbf.

When using the UMK 10, all four measurement points can not be individually zeroed. Therefore a differential approach is used. The zero balance switch on the DMD 20A is set to "off". After the strain transducers have been set up, the numerical values of the four zero signals are measured and recorded. The clamping mechanism of the injection molding machine is activated, whereby a stress is introduced into the columns. The four transducer signals are then measured and recorded. From the difference between the measured values obtained from the loaded and unloaded conditions, the force in each of the four columns can be determined.

Fig. 8 shows a measurement in progress. The clamp-on strain transducers can be seen mounted on the forward columns; the UMK 10 and the DMD 20A instruments can be seen in a protective carrying case on the right. This photograph gives a good impression of the simplicity of this portable measurement system, which can be easily transferred from machine to machine.

The widely used, chain driven mold height adjustment is often the source of problems. The chains wear, fall off, or slip on the adjusting nuts. The resulting unbalance in the column forces is difficult to correct without recourse to some form of measuring instrument. With a quickly fitted strain measuring device is it a simple matter to eliminate any inadvertent incorrect adjustment. The chain is removed and the mold clamping device is actuated. By comparing the force in the four columns, the adjustment of the individual columns can be determined and then corrected with a wrench. After this short interruption in the production the chain can be replaced and tensioned, and the production restarted.

Summary

The preceding discussion described how the manufacturers and the operators of injection molding machines can efficiently guard against equipment damage through the use of simply operated, portable measurement equipment. Worn machines or parts thereof can be economically repaired or maintained

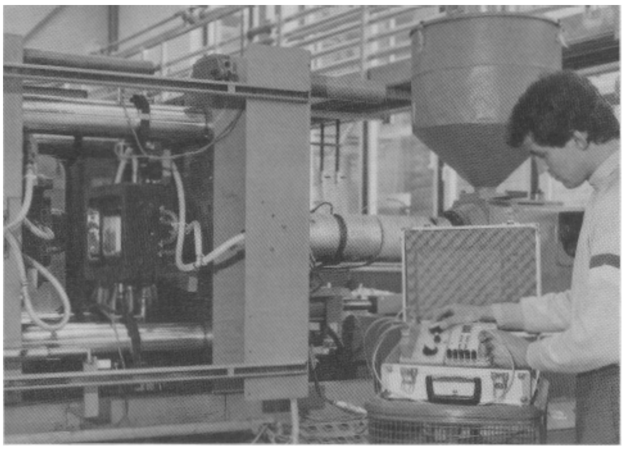

Fig. 8: Taking measurements with strain transducers. The UMK 10 and DMD 20A instruments can be seen in a protective carrying case

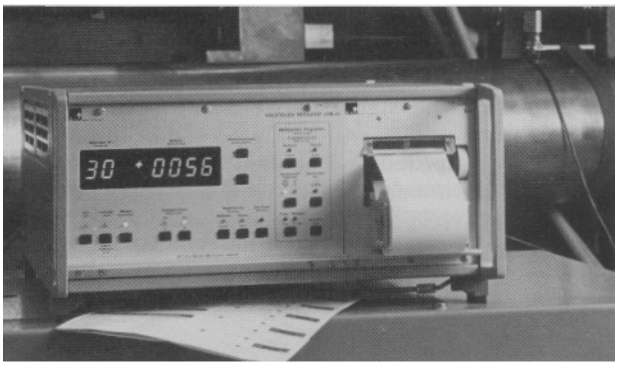

Fig. 9: Type UPM 40A multi-point measuring instrument as a substitute for the UMK 10 and DMD 20A units

with the aid of modern measurement technology. Machine manufacturers can therefore reduce the costs of repairs under guarantee through the sensible application of these techniques.

The experience gathered here can easily be transferred to other machines which suffer similar wear, such as die casting machines, punching machines and presses. The same instrumentation can also be used for other measured variables by employing transducers for force, pressure or torque. This type of instrumentation system can be extremely valuable to those working in the field of maintenance and repair.

In the future it is inevitable that the production of more expensive articles will increasingly demand the use of more expensive machines. Manufacturers and operators are already giving thought as to how the instrumentation systems that have been previously described can be modified for inclusion in the machine's own supervisory system.

The combination of the UMK 10 and DMD 20A units used in the system described in this article has now been superceeded by the UPM 40A multi-point measuring instrument as shown in Fig. 9. It switches to the connected pickups automatically, is able to perform an individual zero balance for each measuring point and prints out the results in the form of a log. Through the standardized communication interface the UPM 40A can also be linked to a computer.

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