HANSER

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Injection Molding Machines

A User's Guide

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Sample Pages

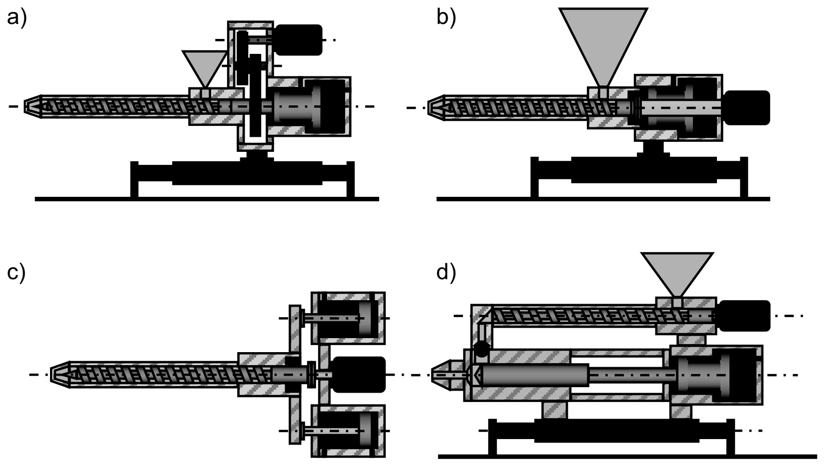


Figure 4.54: Drive systems of injection units; a) Fast rotating electric or hydraulic motor with gear. b) Direct driven screw by an electric or hydraulic motor with slow rotation, c) Two cylinder in paralel position and slow rotating motor, d) Unit with screw plastication and ram injection

4.6.1 Translational Drive System for Screws

Depending on the material employed, specific injection pressures range from 1000 bar right up to, in special cases, more than 3000 bar (see Section 2.1.3). Related to the screw area, this means axial forces of 79 kN for a screw diameter of 20 mm up to 3770 kN for a diameter of 200 mm.

Table 4.19 shows the forces generated when specific injection pressures are built up for different screw diameters. The pressures are adapted to the screw diameter; the application cases for injection molding machines of different sizes require different injection pressures. The injection pressure needs to be maintained during injection, combined with optimum axial speed and injection and screw advance speed.

The injection speed and injection pressure yield a theoretical injection capacity that forms the basis for designing the translational drive. Table 4.20 and Fig. 4.55 show the relationship between the screw diameter, the screw stroke, and the theoretical injection capacity for a given speed and pressure.

4.6.1.1 Hydraulic Drive for Injection Unit

The best drive element for a translational movement offering high force combined with high speed is a hydraulic cylinder (Fig. 4.56). In hydraulically driven injection, the axial movement of the screw is generated by pressurizing a hydraulic cylinder. The resultant axial force, the injection force, is the product of the plunger area x pressure. With the equilibrium of forces follows:

Table 4.19: Injection forces

Screw			Hydraulic cylinder		Transmission ratio
Diameter [mm]	Injection pressure [bar]	Injection force [kN]	Pressure [bar]	Diameter [mm]	
20	2500	**79**	180	75	13.9
30	2200	**156**	180	105	12.2
50	2000	**393**	180	167	11.1
70	1800	**693**	180	221	10.0
100	1500	**1178**	180	289	8.3
150	1400	**2474**	180	418	7.8
200	1200	**3770**	180	516	6.7

Table 4.20: Injection speed and power

Diameter [mm]	Screw stroke 4 × D [mm]	Injection speed [mm/s]	Power [kW]
20	80	150	**12**
30	120	150	**23**
50	200	150	**59**
70	280	150	**104**
100	400	150	**177**
150	600	150	**371**
200	800	150	**565**

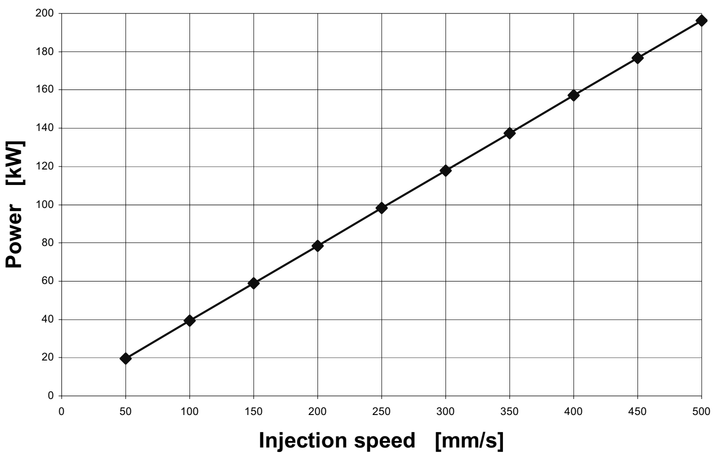


Figure 4.55: Theoretical injection power in relation to injection speed, screw diameter 50 mm, specific injection pressure 2000 bar, injection speed 50 mm/s to 500 mm/s

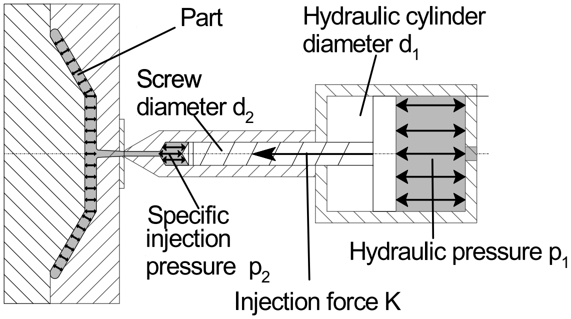


Figure 4.56: Hydraulic power transformation system

$$A_{Screw} \times P_{Specific} = A_{Cylinder} \times p_{Hydraulic}$$

With most injection molding machines, the pressures exerted by the screw on the melt in front of the tip is only indirectly available. The hydraulic pressure in the injection cylinder can be easily measured by means of a pressure sensor and, where necessary, recorded. The relationship between hydraulic pressure and injection pressure (specific injection pressure) depends on the area and thus on the translation ratio:

$$p_{Spezifc} = \frac{A_{Cylinder}}{A_{Screw}} \times pH_{Hydraulic}$$

Usually, three different sets of screw assemblies are offered per machine to enable the utilizable stroke volume to be adapted to the application concerned. The translation ratio changes with the screw diameter (i.e., the conversion factor for hydraulic pressure to injection pressure) has to be adjusted. Because of flow and pressure losses in the nozzle and the gating system, only about 70 % of the pressure in the space in front of the tip is effective in the injection section. Monitoring the hydraulic pressure during injection can, therefore, only be used to obtain qualitative information about the injection process. Table 4.19 shows several screw diameters and the injection pressure resulting from a preset translation ratio and a hydraulic pressure of 180 bar. The relatively high specific pressures chosen correspond to the screw barrel with the smallest screw diameter for each machine size.

4.6.1.2 Electromotive Drive for Injection

The recent development of stronger and more accurate electric servomotors has created the groundwork for realizing linear electromechanical screw movement. Basically, electromotive linear drives are an added disadvantage to hydraulic cylinders when it comes to building up the high forces necessary for injection (Table 4.19). However, they offer major advantages in terms of stiffness of force transmission and accuracy, as well as ease of control. Development work has focused on implementing the rotary motion into a linear motion. Ball screws have become the standard component. Other, technically more sophisticated, approaches use levers or an eccentric to implement the linear motion (Fig. 4.57). Table 4.21 gives a comparison between these different electromechanical drives for linear screw driving.

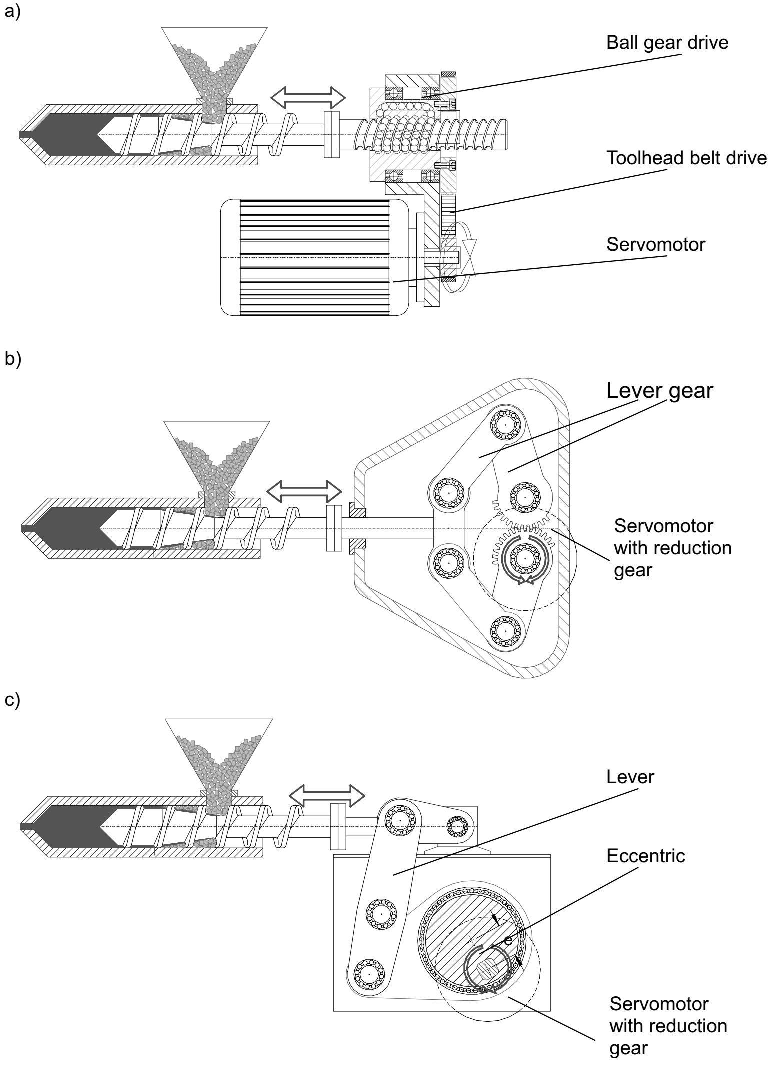
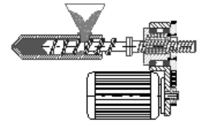
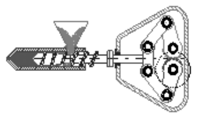
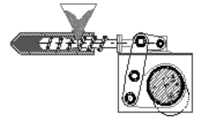
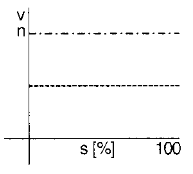
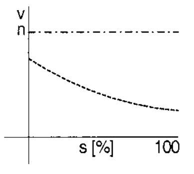
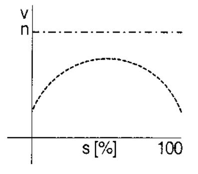
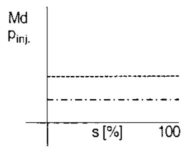
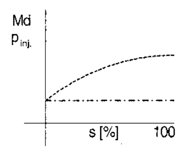
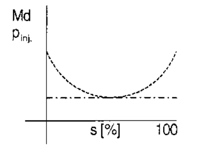


Figure 4.57: Linear electromechanical screw drives for injection; a: standard solution, ball gear drive with servomotor and toothed belt; b: lever concept (Ferromatik Milacron); c: eccentric concept (Netstal)

Table 4.21: Comparison of different linear electromechanical drives for screws

	 Ball screw drive with toothed belt **(Standard system)**	 Crank lever drive, elanetary gear drive **(Ferromatik Milacron system)**	 Crank lever drive, eccentric drive **(Netstal system)**
Injection speed at constant motor speed (rpm) Use of total screw stroke			
Injection pressure during constant motor speed (rpm) Use of total screw stroke			
Accuracy	100	100	100
Costs	100	125	130
Maintenance	100	100	100
Efficiency	100	90	80

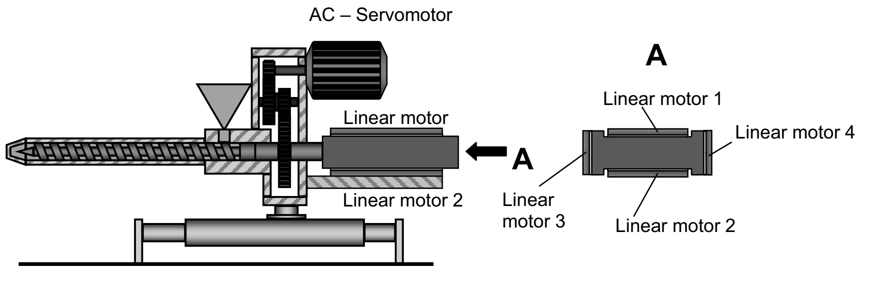


Figure 4.58: Electromechanical drive with four linear motors (Fanuc system)

Another technical solution is the use of electric linear motors as proposed by Fanuc. Here, the axial movement of the screw is generated by four linear motors connected in parallel (Fig. 4.58). The technical data of this injection molding machine (manufacturer's data):

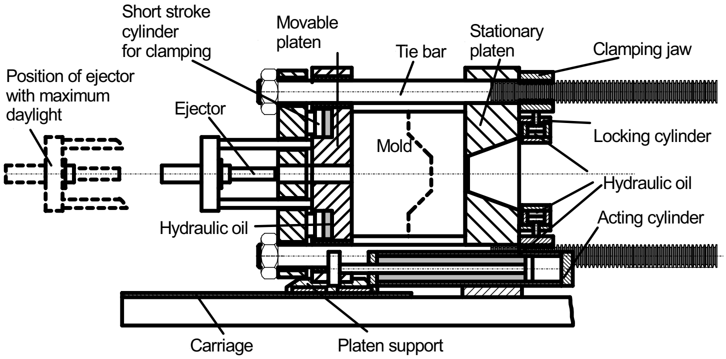


Figure 5.18: Clamping unit with two platen and cushion in support platen, split nuts

Advantages
- Short construction
- Central introduction of force into MMP
- Good accessibility to ejector
- Short oil column → rigid

Disadvantages
- Co-travelling tie-bars
- Co-travelling hydraulic elements
- Larger moved weights
- Restricted accessibility to machine nozzle
- Complex sandwich platen

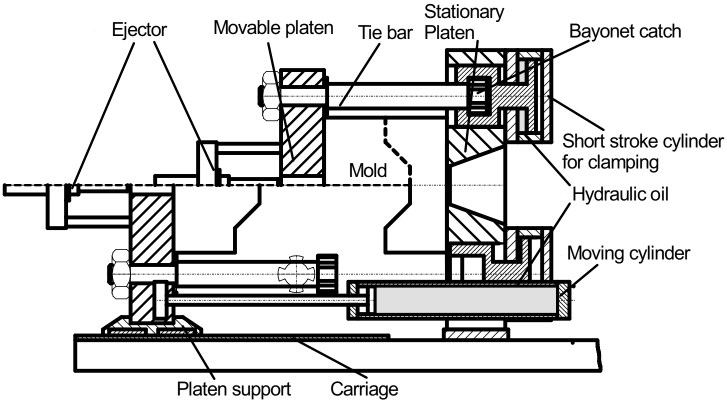


Figure 5.19: Clamping unit with two platens and chuck locking, four cushions on tie-bars, chuck with bayonet catch

Advantages
- Short construction
- Good accessibility to ejector and machine nozzle
- Good accessibility to mold when tie-bars retracted
- Short oil column → rigid
- Most experience gained with this type of two-platen clamping unit

Disadvantages
- Co-travelling tie-bars
- Complex part for anchoring tie-bars and building up clamping force
- Larger moved weights
- No additional guides
- Tilting moment on MMP

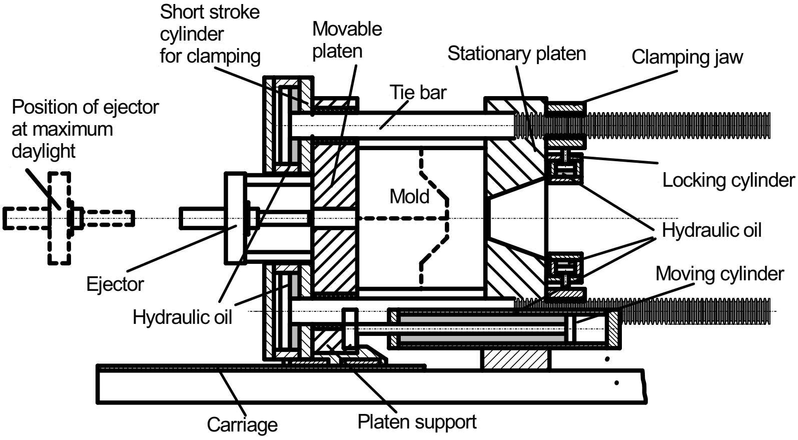


Figure 5.20: Clamping unit with two platens and four cushions on tie-bars, clamping jaw

Advantages
- Short construction
- Good accessibility to ejector
- Simple parts for the separate functions: Locking/clamping
- Short oil column → rigid

Disadvantages
- Co-travelling tie-bars not firmly anchored (floating)
- Co-travelling hydraulic parts
- Larger moved weights
- No support for tie-bars
- Restricted accessibility to machine nozzle

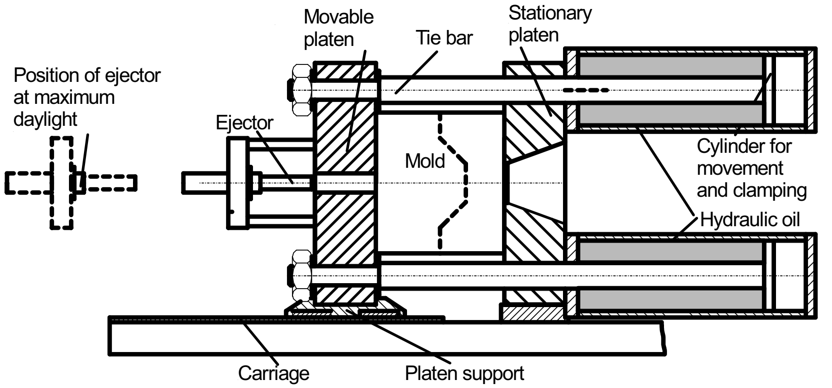


Figure 5.21: Detached clamping unit with movable tie-bars, direct hydraulic actuation

Advantages
- Short construction
- Good accessibility to ejector
- Function: No locking
- Simple mold height adjustment

Disadvantages
- Co-travelling tie-bars
- Poor accessibility to machine nozzle
- Long oil column → elastic
- Slow build-up of clamping force

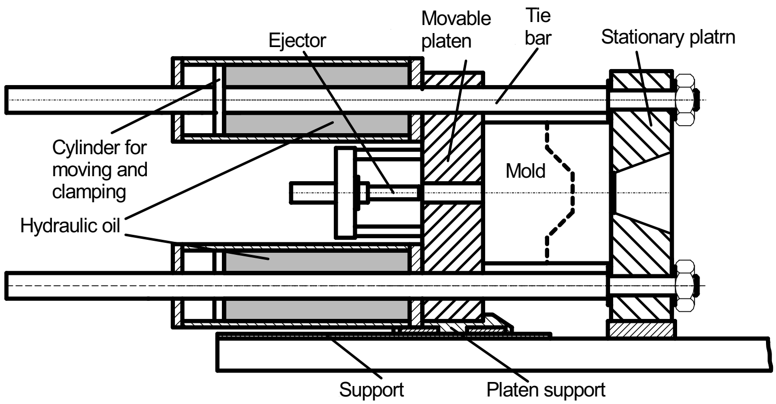


Figure 5.22: Detached clamping unit with movable tie-bars, direct-hydraulic actuation

Advantages
- Good accessibility to machine nozzle
- Simple mold height adjustment
- Function: No locking
- Stationary tie-bars anchored in SMP

Disadvantages
- Longer construction
- Co-travelling hydraulic parts
- Restricted accessibility to ejector
- Long oil column → elastic
- Slow build up of clamping force

5.3.3 Tie-Bar-Less Clamping Units

Tie-bar-less clamping units have been used as presses for years in rubber and thermoset processing. Because of the good accessibility afforded by this design, it has proved its worth in practice and is an economic success. The company Engel presented the first horizontal 500-kN machine as a tie-bar-less model in 1989. This range now spans clamping forces from 200 to 6000 kN. The enormous, spontaneous economic success has induced a number of other machine manufacturers to offer tie-bar-less models (Figs. 5.23 to 5.26).

Advantages

- Large clamping area for the mold
- No tie-bars to hamper accessibility
- Surface of mold platens fully utilizable
- Different-size clamping platens are easy to exchange
- Parts insertion and removal are easily automated
- Simple set-up of bulky molds
- No tie-bar lubrication
- Very good plane-parallelism of platens under all load stages
- Less deformation of stationary platen given linear bearings on the frame (as opposed to 4-point bearings)

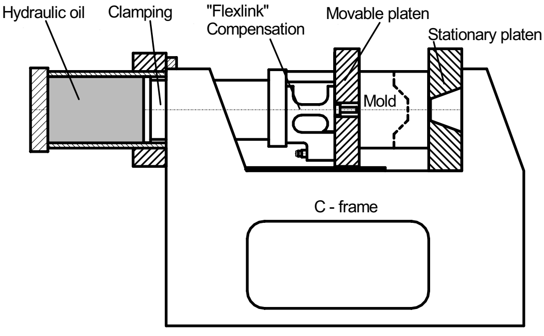


Figure 5.23: Tie-bar-less clamping unit in C frame (Engel system)

Advantages

- Very good accessibility to mold
- Good automatic plane-parallelism of the MPs
- No tie-bars
- High platen rigidity
- Removal easily automated
- Large mold height
- Simple mold height adjustment

Disadvantages

- Longer construction
- Poor accessibility to ejector and machine nozzle
- High machine weight
- Long oil column → elastic
- Slow build up of clamping force

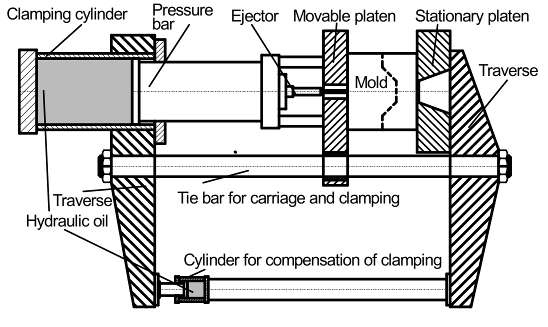


Figure 5.24: Tie-bar-less clamping unit in H frame

Advantages

- Very good accessibility to mold
- Automatic plane-parallelism of MPs
- No tie-bars in mold area
- High platen rigidity
- Removal easily automated
- Large mold height
- Simple mold height adjustment
- Good accessibility to ejector
- Good guiding of MMP
- Force compensation through compensation element

Disadvantages

- Longer construction
- Long oil column → elastic
- Complex force compensation
- Tie-bars designed for almost twice the clamping force
- Unstable machine bed
- Slow build up of clamping force

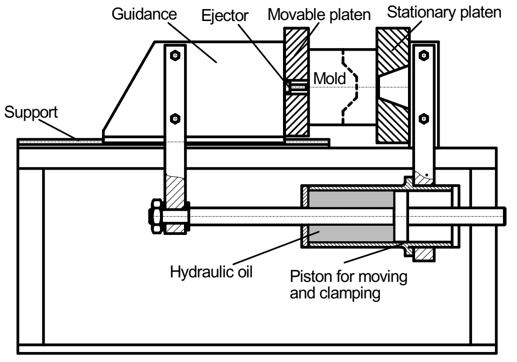


Figure 5.25: Clamping unit without tie-bars in vise framework

Advantages
- Simple construction
- Good suitability for smallest of machines
- Very good accessibility to mold
- Simple mold height adjustment

Disadvantages
- Longer construction
- Poor accessibility to ejector
- Long oil column → elastic
- Slow build up of clamping force
- Deflection of the machine bed by clamping force
- Load on guides from clamping force

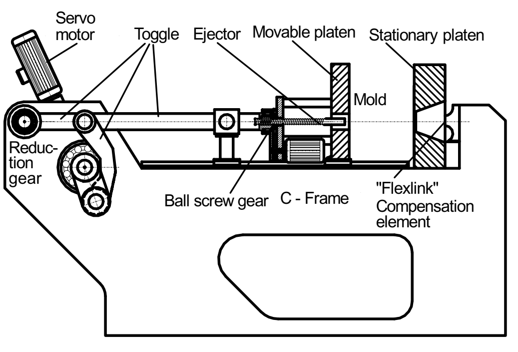


Figure 5.26: Tie-bar-less clamping unit in C frame with electromechanical drive and "Flexlink" compensation element (Engel system)

Advantages
- Very good accessibility to mold
- Good automatic plane-parallelism of the MPs
- No tie-bars
- High platen rigidity
- Removal easily automated
- Large mold height
- Simple mold height adjustment
- Low energy consumption

Disadvantages
- Longer construction
- Complex design → high costs
- Poor accessibility to machine nozzle
- High machine weight

Disadvantages

- Relatively high weight of the machines (clamping frame dimensioned for moment load, whereas tie-bars dimensioned for tensile load)
- Restricted accessibility of machine nozzle because of frame construction
- Partial restrictions on accessibility to ejector mechanism
- Injection-compression molding limited: During the compression process, there is little or no guiding of the mold halves toward each other, the extent depending on the design of the clamping unit; especially in the case of eccentric loads, extremely good guidance is needed inside the mold design

Compared with hydromechanical tie-bar-guided (toggle) clamping units, there is much more in driving tie-bar-less clamping units electromechanically. Engel has been offering this kind of clamping unit since 2001.

Figure 5.26 shows the design: the main drive is a combination of servo motor and speed reduction gear that drives a crank arm.

5.3.4 Special Clamping Units for Production of Compact Discs

Optical data carriers, such as CDs and DVDs, were originally produced on standard injection molding machines. Because of the high technical specifications and the demand for increasing output, special designs tailored to this application are now used all around the world (Figs. 5.27 to 5.29). The precision required for DVD production can only be accomplished in an injection-compression molding process. New machine designs for this application are exclusively electromechanical.

The clamping unit shown in Fig. 5.27 is designed for maximum production speed combined with high precision. It is driven by a servo motor and a reduction gear that turns an eccenter. Since the eccenter can only perform a short stroke for the rapid movement, the stationary platen has to be traversed to the right whenever mold changes or service work on the mold is needed. This is performed by means of an electro-motor that turns the tie-bars by means of a toothed belt. The thread on the nozzle side of the tie-bar ends and the nut and the platen produce the axial movement.

The clamping unit shown in Fig. 5.28 has a totally different design. It employs the least number of individual parts possible. It has an electromechanical two-platen clamping unit. It is driven by four servo motors, with the nuts rotating on the tie-bar ends. The tie-bar ends are shaped as threads so that the rotary motion produces an axial motion on the movable platen. Here, too, high movement speeds are attained. An additional advantage is that any non-parallelism can be compensated by the servo motors.

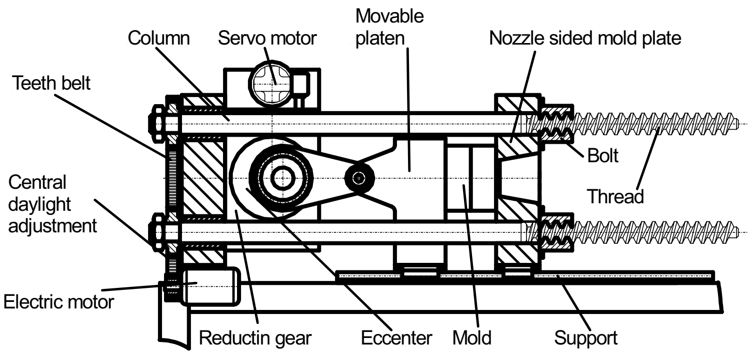


Figure 5.27: Clamping unit with direct electromechanical eccentric drive for CD production (Netstal Patent WO 00/47389)

Advantages
- High opening and closing speed
- Optimum speed profile for compression
- Short construction
- High precision
- Low energy consumption

Disadvantages
- Complex construction
- Poor accessibility to ejector
- Tie-bars not clamped on both sides

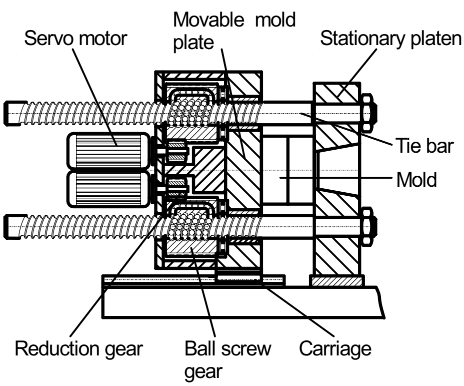


Figure 5.28: Clamping unit with direct electromechanical spindle drive for CD production (Newtoms system)

Advantages
- Few parts
- Short construction
- Correction capability for parallelism
- Tie-bars firmly clamped into SMP
- High precision
- Low energy consumption

Disadvantages
- Four servo motors → expensive
- Complex control mechanism for parallel operation
- Poor accessibility to ejector

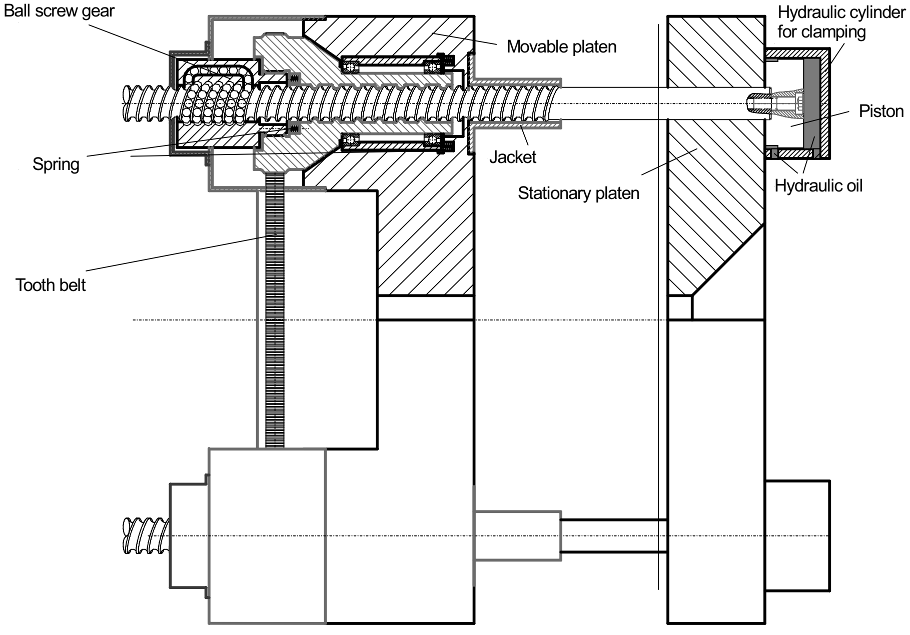


Figure 5.29: Hybrid clamping unit for CD (DVD) machine with electrically driven spindle for movement, and oil cylinder for clamping (Eltec model from Krauss Maffei)

Advantages
- Short construction
- Fast cycling possible
- Correction capability for parallelism
- High precision
- Low energy consumption

Disadvantages
- Expensive
- Control mechanism necessary for parallel operation
- Tie-bars not clamped on both sides

5.4 Accessories for the Clamping Unit

Injection molding machines are automatons. The reason that they are often not operated in this mode is that the equipment does not allow it. Accessories must always meet the demand for automatic operation. This especially applies to plastic feed and parts removal and transportation.

A further rationalization effect can be achieved by reducing downtimes during mold changing. The technical options for doing this range from using mechanical or hydraulic clamping elements through to automated changing systems. The connecting elements for the electrics, hydraulics, and temperature control have to be included. The range of equipment for the clamping side of machines that meet today's needs comprises accessories that may be divided into two segments: standard equipment and optional accessories. Standard accessories can rarely be dispensed with, and the benefits of investing in one or more of the items listed as special accessories needs to be evaluated on merit.

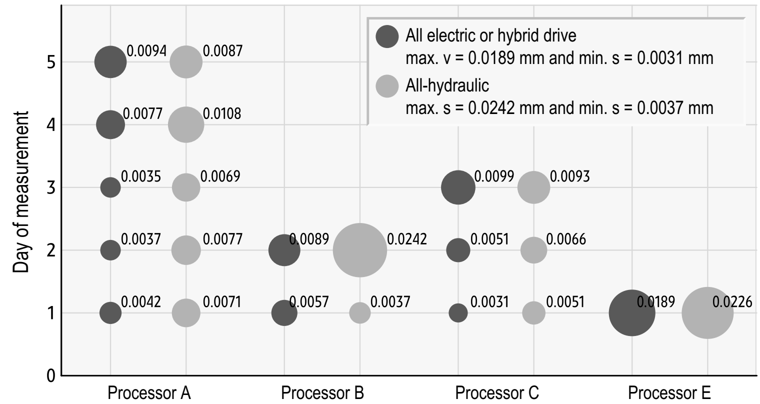


Figure 6.33: Scatter of molded part dimensions as determined at different companies over several days [17]

- Power is supplied in line with consumption and without idling losses → up to 50 % lower energy consumption (see Section 8.1)
- Good efficiency → No cooling water consumption, low heat reflection
- Particularly accurate operation, repeatability (position, cycle time) roughly twice as good → High-quality molded parts, less scrap (see Fig. 6.33)
- Noise emissions low →< 60 dB (A)
- Oil-free operation possible → No oil management needed at all

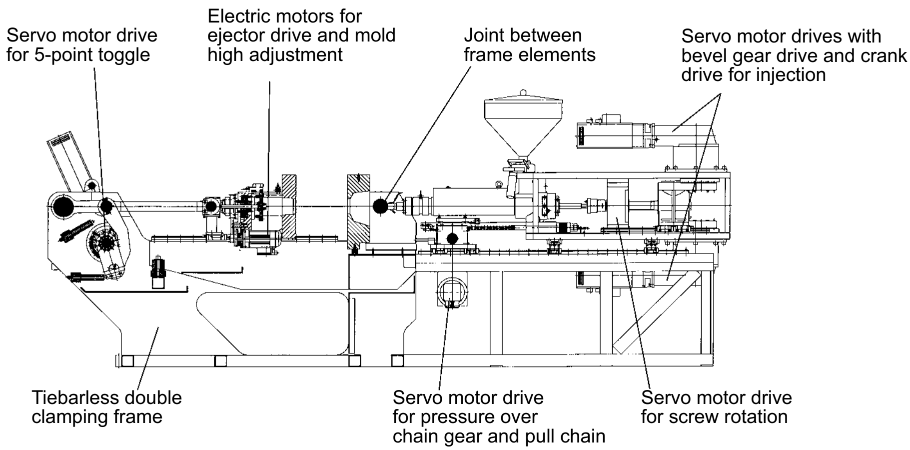


Figure 6.34: Tie-barless injection molding machine with electromechanical drive Model ES 650/110 TL (Engel system)

- Cleanroom conditions can be satisfied more easily
- Maintenance limited to electrics in large factories, experts will be available → Less maintenance outlay

The latter advantages can only be fully exploited if machines with direct-electric drives are not installed in a unit with conventional machines. The full benefit is gained by setting up a new production line with electromechanical machines in a separate production unit. This could, for example, be a cleanroom for making medical products, optical products, or optical data carriers.

The most common arrangement of an electromechanically driven injection molding machine nowadays has several motors that drive just one or at most two axes (and only in parallel at that). This approach requires only a few translation parts, usually toggles and threaded spindles. Transfer is virtually 100 %.

One of the latest products is a tiebarless machine with an electromechanical drive and a special toggle technology as presented in 2000 (Fig. 6.34).

6.2.1 Mechanical Gears for Electromechanical Drives

Plastication with a screw requires a rotary drive. Electric drives are often the most suitable, and they are simple to install. Gear wheels and toothed-belt drives serve as the speed-reduction gear. This type of drive is more efficient than a hydraulic motor, which would require energy conversion in the pump and motor. Nearly every machine builder now makes this hybrid drive, called "hybrid" because it uses different drives to rotate the screw and to perform other functions.

Except for the plastication step, all the functions in an injection molding machine require translational motion that has to be driven, monitored, and controlled. The forces and motion speeds vary over a wide range. Translating the rotation of the electric motor into translational motion requires very completed mechanics and increases the machine's production costs.

The standard element for translational motions is the ball screw (or spindle) drive or the planetary roller drive. The high speeds of the electric motor are reduced by means of a toothed-belt drive with fixed speed reduction (Fig. 6.35). Figure 6.36 shows a ball spindle drive that employs so-called caged ball technology. This is a ball or chain screw drive in which the distance between the balls is fixed and direct mutual contact between them is prevented. Wear and overall friction are relatively low and that increases the service life.

The spindle drive may equally be used for the injection unit (Figs. 6.35 to 6.38) and the clamping unit (Fig. 6.39). The ball screw drive, especially, is limited in its maximum speed. This fact led to the development of high-performance injection molding machines in which spur gears or toggle mechanisms convert the rotation of the electric motor into translation (e.g., of the clamping unit or injection screw). Further designs have been developed, partly to circumvent patents and partly to improve on existing solutions.

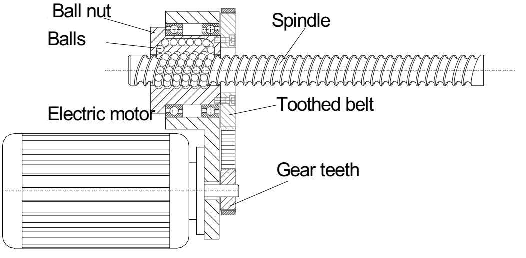


Figure 6.35: Ball screw drive with toothed-belt reduction

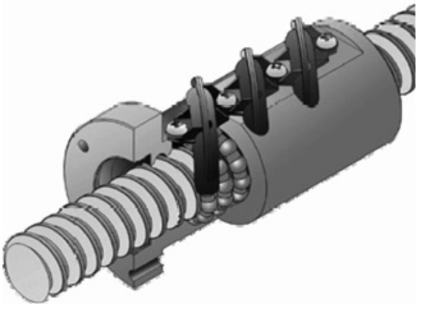


Figure 6.36: Ball spindle drive with caged ball technology and high bearing (THK system)

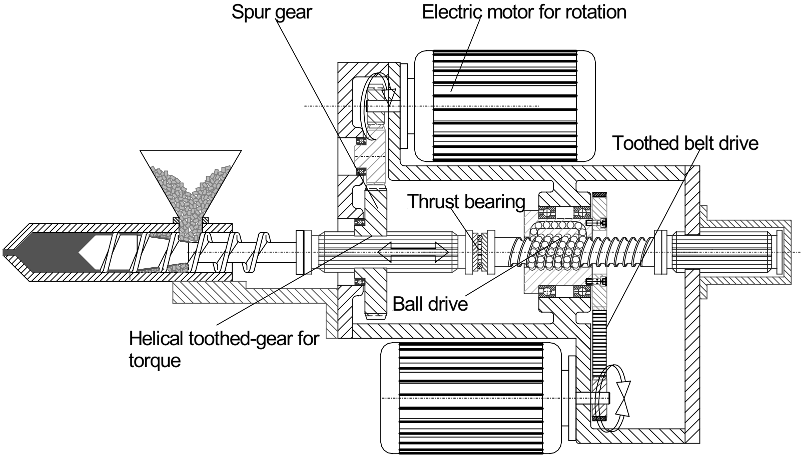


Figure 6.37: Electromechanical drive for the injection unit with spur gear for rotation and ball drive for injection [1]

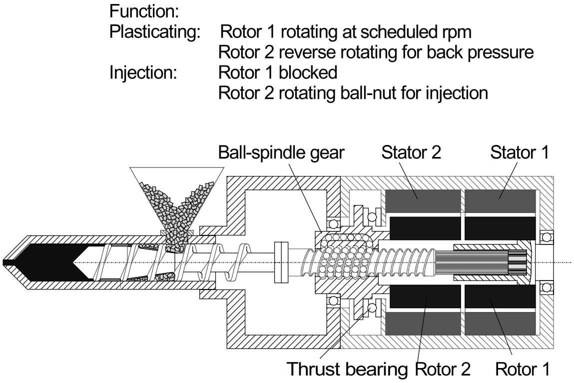


Figure 6.38: Direct screw drive for rotation and injection (Eltec Krauss Maffei system)

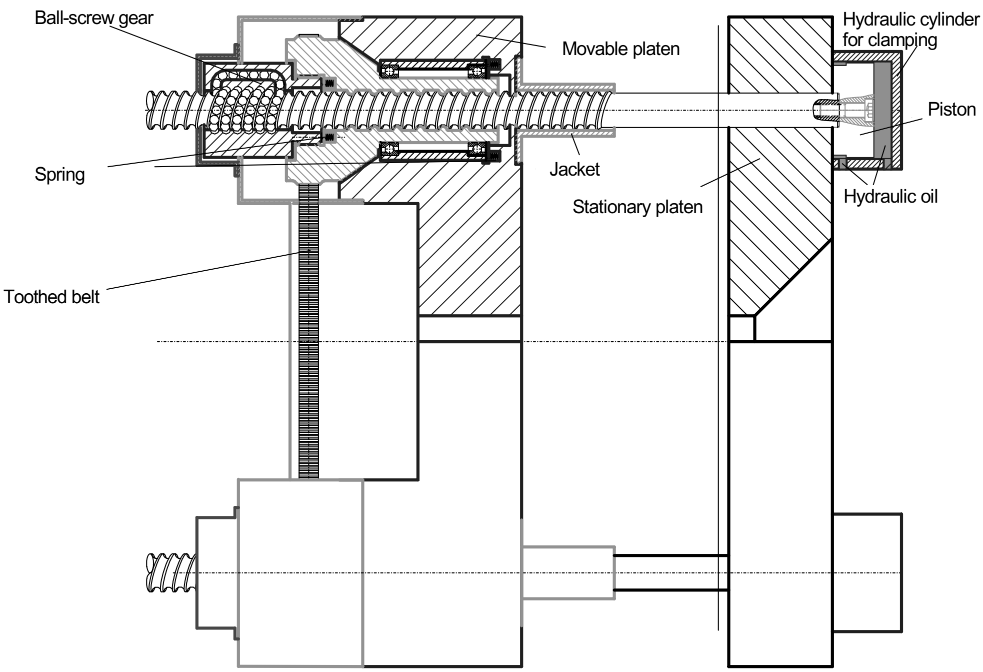


Figure 6.39: Ball screw drive for clamping (Krauss Maffei system)

The drive shown in Fig. 6.37 works as follows:

Injection:

As an extension of the screw, the screw coupling is connected with the injection spindle, which is connected with the plasticating motor through the injection motor. The stem nut into which the spindle projects is mounted on the rotor of the injection motor. As the rotor of the injection motor turns, the stem nut turns and moves the spindle and thus the screw in a translational direction. The spindle is held by means of an idler to prevent the screw from rotating during injection. The plasticating motor is at a standstill during the injection process.

Holding pressure:

While during injection the set speed or rpm is under closed-loop control, during the holding-pressure stage, it is the pressure or the torque of the injection motor that is under closed-loop control. The injection motor is kept at the requisite torque by the level set for the holding pressure.

If the ball screw drive, including the toothed belt, is replaced by a spur drive with rack and pinion, much higher speeds can be achieved (Fig. 6.40). A toggle gear in combination with a planetary gear and a servo motor provides an optimum speed profile for the injection process. Again, with this solution, there is no system restriction on speed (Fig. 6.41).

Very high motion speeds combined with an optimum speed profile can be achieved with an eccentric drive. Since the eccentric for a large stroke would be too large, this design is used especially on injection molding machines for making optical data carriers, such as CDs and DVDs. The clamping unit has a stroke of around 600 mm (Fig. 6.42).

When it finally becomes possible to use the four-linear-motor design on injection molding machines at a reasonable cost, electromechanical drives will advance into the area of linear motion as well. They do not require any conversion of rotation into translation, and they have many fewer parts and can reach injection speeds of 2000 mm/s in 0.017 s with a screw of 18 mm diameter (according to manufacturer Fanuc). This solution, combined with the known advantages of electromechanical machines, is ideal for the optical data carrier market.

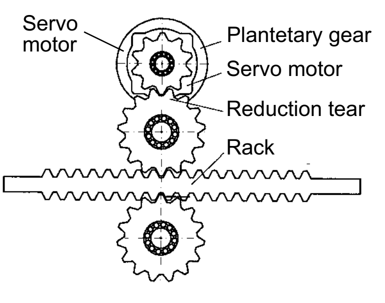


Figure 6.40: Servo motor with planetary gear and rack [1]

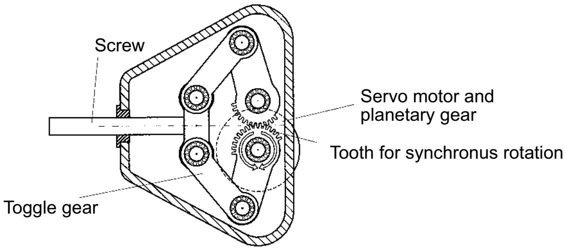


Figure 6.41: Servo motor and toggle gear for injection (Ferromatik Milacron system)

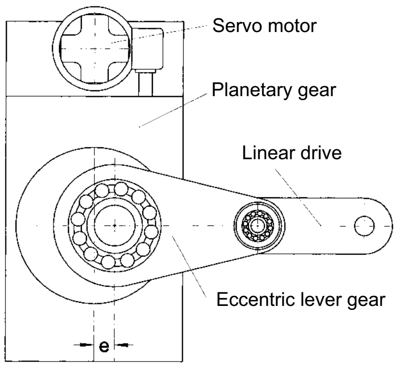


Figure 6.42: Linear drive with servo motor, planetary gear, and eccentric lever gear (Netstal system)

6.2.2 Elements of Electromechanical Drives

6.2.2.1 Electric Motors

Polyphase Induction Motors

Typically, polyphase squirrel-cage motors serve as power generators because of their constant speed during continuous operation and their rugged construction. This is the classical case for an electrohydraulic drive, where electrical energy is converted into hydraulic energy, and a hydraulic pump, or a combination of pumps, is coupled to the motor.

These motors have a starting torque of about 1.5 times the full load torque at rated voltage. The locked rotor currents vary between four and seven times the full-load current. With motors of larger size (i.e., more than 370 kW (200 bhp)) reduced voltage may be necessary to meet starting-current restrictions. This is commonly achieved by means of a compensator or autotransformer. In the starting position, a Y connection is made across the line supplying the motor with reduced voltage. In accordance with the starting current, the starting torque is reduced to about one third of that from a direct connection. Since hydraulic pumps are not started under full load, this is the preferred method.

Table 6.4: Converter circuits for three-phase AC motors

Converter type	Converter with direct-voltage intermediate circuit	Converter with direct-voltage intermediate circuit
Control method	Frequency change and voltage control, pulse-width control to provide sine-shaped current	Frequency change and current control
Frequency range	2.5 … 120 Hz	5 Hz … 50 Hz 5 Hz … 87 Hz
Load range	1.5 kW … 171 kW	16.5 kW … 50 kW 50 kW … 1050 kW
Typical rpm range	1:200	1:20
Motor type	Three-phase squirrel-cage motor	Three-phase squirrel-cage motor
Motors per converter	1 or more	1
Applications	Feeding devices, screws, conveyers, fans, mixers, machine tools	Blowers, fans, pumps, mixers, screws, conveyers belts, presses

Motors can operate with a higher locked rotor torque for a short time. This is called working with an overload margin. The nameplates of such polyphase induction motors carry a code and a design letter. The latter (A to D) provides information about torque characteristics. Thus, the upper limits of the locked rotor torque of a 100 bhp (75 kW) motor are (A) 125 %, (B) 125 %, (C) 200 %, and (D) 275 % of the rated torque. This is particularly advantageous if load surges occur during intermittent operation. Consequently, overload is permissible during the brief injection stage and an electric motor of 30 kW can drive a hydraulic pump up to 48 kW.

On the other hand, the efficiency curve for the range of rated loading is fairly flat and the economics of asynchronous motors are not considerably reduced if they are oversized for reasons of safety. By switching poles, two speeds in a ratio of 2:1 are readily obtained with induction motors. Thus, 3000 rpm can be reduced to 1500 rpm and 1500 rpm to 750 rpm. Motors with two windings even allow four speeds. It should be kept in mind that this is a compromise and may sacrifice desirable characteristics. At any rate, it may occasionally be adequate for the screw drives of simple injection molding machines.

Synchronous polyphase motors mostly serve as the main drive in the power range exceeding 100 kW. Below this, the rugged asynchronous squirrel-cage motor dominates because of its price advantage. The supply for synchronous motors is taken from a synchronous converter as shown in Table 6.4. It is integrated into the motor and delivers direct current for the armature winding.