

The Development of Injection Moulding

Retrospective. For many years, the development of injection moulding has paralleled the development of polymers. The basic technology for today's highly complex and fully automatic production machines traces its origin back to 1872.

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Bock divides the history of injection moulding into five eras [1]. This division is retained here with some additions, so that the attentive observer of this branch of industry can follow very easily over the course of years the topics being discussed. A total of eight development stages can be distinguished, of which the first four are treated in a more detailed manner here:

- Predecessors; the hand-operated and the mechanised injection moulding machines (IMMs) with and without automatic sequence control (1878 to 1931)
- IMMs with plunger plasticising and electromechanical (so-called "fully electric") or electrohydraulic (so-called "hydraulic") drive (1932 to 1950)
- IMMs with preplasticising and plunger injection (1950 to 1956)
- IMMs with a screw-equipped assembly for melting and injection, the screw having either electric (so-called "hybrid machine") or hydraulic drive (since 1956)
- Automation of IMMs, machines with closed-loop control (since 1960)
- Process control (since 1970)
- Automated injection moulding plants (since 1980)
- Massive introduction of special techniques (since 1985, some already since 1970)

Predecessors from the Diecasting Sector

In the middle of the 19th century, diecasting originated in conjunction with production of metal type for the printing industry. At the beginning of the 20th century, the processing and design prin-

ciples of diecasting were adopted directly for construction of injection moulding machines [1, 2, 4]. Even in the very early years, the idea arose to produce "custom-made parts" from a "custom-made material". This degree of perfection has been available for about 10 to 20 years and was achieved specifically through the introduction of numerous special techniques (processes). The quality of this technology is confirmed by the fact that, at present, it is being employed increasingly with success in the metalworking industry.

Injection moulding of plastics begins with a zoological anecdote. In the year

1868 ivory was in short supply. Production of billiard balls out of ivory was not able to meet the immensely growing demand, especially in the "New World". The American company Phelan and Collander offered a large prize to the individual who invented a substitute for ivory [2, 3]. Feverish activity ensued, and only one year later the printer John Wesley Hyatt produced on an industrial scale the material still called celluloid today from nitrocellulose and camphor. Thus, in 1869 a plastic functioned for the first time as an environment-preserving material, since celluloid saved elephants from extinction. In the year 1872, J. W. Hyatt and his brother received a patent in the USA for an injection machine to process celluloid (US Patent 133229) [1–8]. The machine (Fig. 1), which was subsequently built by Hyatt, exhibited all of the features of a vertical injection moulding machine.

Hyatt was surely aware of techniques for moulding brush handles, clasp and billiard balls from casein resin and likely recalled machines for metal diecasting, which existed since 1849.

According to reports, several Hyatt machines were built and operated up until about the turn of the century. In 1878 these machines were used for the first time to mould handles for shaving brushes; this represents the first moulding around cores. However, the lack of suitable injection moulding compounds prevented the success of these fully developed machines and they were forgotten completely. In 1942 they once again played an important role in the USA in a patent dispute that had significantly slowed the development of injection moulding in the USA for more than a decade when it was proven that in 1908 the Burroughs Company had built three machines on the basis of the Hyatt patent. This ended all patent disputes.

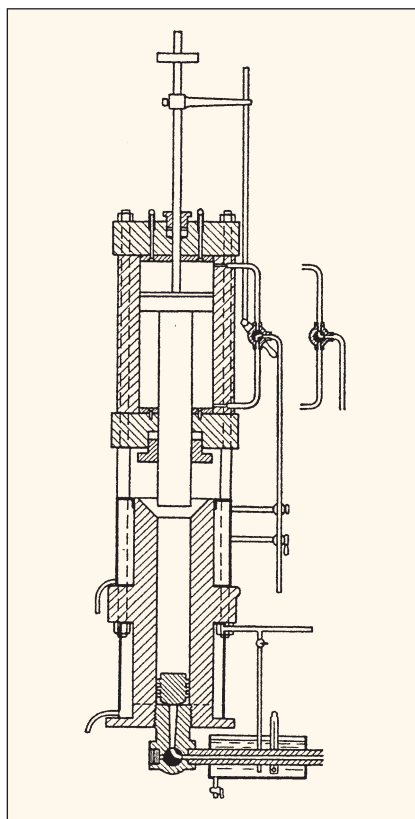


Fig. 1. Injection machine for which the Hyatt brothers filed a patent, with hydraulically actuated plunger and steam-heated barrel [1, 2]

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Plunger Plasticising with an Electromechanical or Electrohydraulic Drive

While the machine (Fig. 1) patented by the Grotelite Company, USA, prevented all further development in the USA, an advancement occurred that for German machine builders is even more important with respect to their image today. With the machine developed by Buchholz (Fig. 2) and the first hydraulic machine (Fig. 3), the state represented by the Hyatt machine had been reached almost once again. The injection plunger also generated the clamping force.

Starting about 1920, the intimate connection between production of plastics and processing of plastics during this initial stage is exemplary. It continued until about 1956. Even thereafter, however, it can be observed that materials influenced or made processes possible and, conversely, functioning processes called for new plastics.

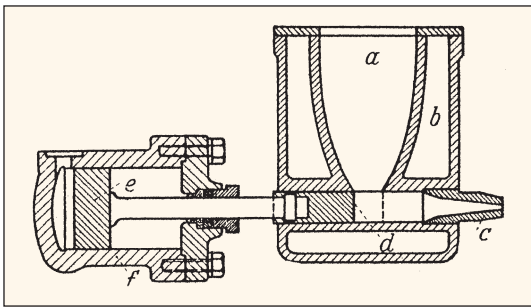


Fig. 3. First horizontal injection moulding machine with hydraulic actuation of the injection plunger; German Patent DRP 470 104 [2]

The patent application by Vorrarber in 1905 is an unresolved episode. His patent claimed quite clearly a barrel with a rotating and axially moving screw. It can no longer be explained today why this interesting patent remained neglected and was forgotten by the experts of the time. One possible explanation could be that there was simply no need for processing machines because of the paucity of plastics. There is a further example with regard to the development of the screw concept. In 1927, Eckert & Ziegler applied for a patent for the intrusion process. It was only after 1958, however, that it was used for production of thick-walled PVC parts.

A very detailed and informative description of the development of injection moulding technology, especially regarding machinery, is contained in reference [2]. This book provides a complete overview of all machines and the injection mould-

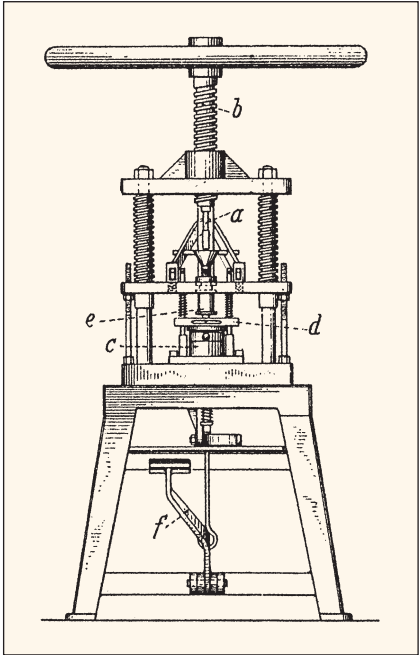


Fig. 2. Vertical injection moulding machine of H. Buchholz from the year 1923, US Patent 1 810 126 [1, 2]; a: plunger, b: spindle, c, d: mould, e: heated barrel, f: foot-operated lever

ing compounds of choice that were available around the world in 1956. The book is of historical value because of the complete listing of patents up to 1959 and the information that in 1959 – Laeis actually surveyed the entire injection moulding universe – there were 90 machine builders in the entire world (Table 1).

The book by Bock [1] supplements this in a very detailed manner with the situa-

tion in Eastern Germany before and during the GDR era. The KuSYA brand (Kunststoff-Spritzguss-hydraulisch-Automat, later KuASY) was important for the injection moulding machine building industry in the GDR, and especially the Eastern European economies.

Another equally important description of the course of development taken by injection moulding is provided in the work by Sonntag from 1985 [6]. A retrospective that focuses very much on individuals and their involvement was published by Wobken [9], who documented how several very ingenious inventors made injection moulding history, but did not always receive recognition [see also 8].

As A. Eichengrün presented the acetylcellulose compound “Lonarit” in 1919 (later “Trolitul”) and, at about the same time, the previous Friedrich Bayer & Co. introduced “Cellit”, the first injection moulding machine was invented in Germany. It was Eichengrün, who in 1919 patented the basic concept of injection moulding with German patent DRP 395084. This patent and others later passed into possession of Dynamit AG, Troisdorf, which then contributed to the breakthrough of injection moulding with the acetate injection moulding compound “Trolit”.

In 1921 H. Buchholz built a hand-operated injection moulding machine (Fig. 2) that, unfortunately, was used only in his own factory. The Eckert Company, originally a manufacturer of metal diecasting machines, introduced to the market in 1923 a similar machine in which likewise the nozzle closed the mould. This machine was capable of pro-

Country	Number of manufacturers in the year		Number of machine models manufactured	
	1955/56	1959	1955/56	1959
Australia	1	1	4	9
Denmark	–	1	–	2
Germany (incl. GDR)	18	25	97	150
France	9	15	30	43
Great Britain	12	8	28	32
Italy	5	11	39	110
Japan	3	3	11	21
Austria	–	2	–	12
Schweden	–	1	–	5
Switzerland	1	1	3	6
Spain	5	5	19	15
USA	11	17	62	97
Total	65	90	293	502

Table 1. Injection moulding machine manufacturers – 1955 to 1959 [2]

ducing plastic parts weighing between 10 and 12 g. With its vertical design, it strongly resembled Hyatt's machine, electrical bobbins were one of the primary applications. Fig. 3 shows the first horizontal injection moulding machine.

Chemists were the first to recognise that to process plastics special techniques on appropriately designed machines were needed. How extensively in the 1930s both the moulding compounds and the articles produced from them were described can be seen in this excerpt from

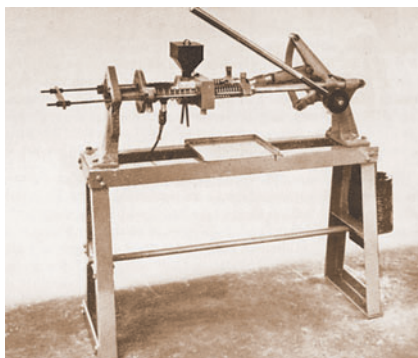


Fig. 4. First series-produced injection moulding machine [3]

an article by A. Herz in the June 1933 issue of the magazine **Kunststoffe**:

„[...] While the prices of plastics such as celluloid, Cellon, artificial horn, hard rubber and synthetic compression moulding compounds [...] have dropped considerably because of the increased competition, the raw material prices for the two injection moulding compounds Trolit and Trolitul have remained high. [...] As a result, injection moulding no longer represents an economically viable method for producing parts for which the material properties of other plastics (moulding materials) suffice [...], e.g. clasps, buttons, powder, cosmetic and jewelry cases, toy figures, switch levers, pushbuttons, handles for tools and cutlery, small appliance housings. [...]”

Judging from the above report, injection moulding was not immediately considered superior to the well-known technique of compression moulding. In fact, even today compression moulding of thermosets has not been completely replaced [10]. The following can be read in issue 6 of **Kunststoffe** as early as 1935: “The development of injection moulding of thermoplastics has shown that [...] in spite of the considerably higher price compared to compression moulding compounds, the process is not only suc-

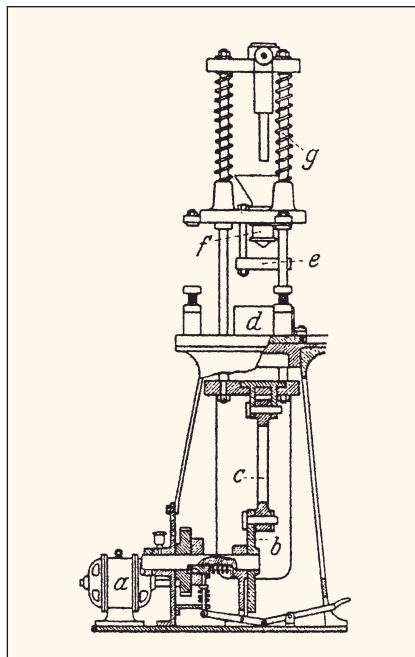


Fig. 5. Automatic injection moulding machine of K. Welscher, Berlin, German Patent DRP 468 754 from 1926 [2]; a: electric motor, b: eccentric plate, c: crankshaft, d, f: mould halves, g: injection plunger

ceeding, but even exhibits a definite upwards trend”. The reasons for this were given as: “the moulding compounds have

been improved” and “higher production output”. Neither is surprising.

The second chapter in the history of injection moulding begins about 1920 – the age of plunger injection moulding machines for industrial use. The spindle-operated injection moulding machine built by Buchholz with the assistance of Eichengrün in 1921 (Fig. 2) had no market impact whatsoever, since it was used only in the factory of its builder. The Grotelite Company, however, successfully built this machine in the USA on the basis of the Buchholz patent. Even the machine built in 1922/23 by the Eckert brothers in Nuremberg was of no importance to the market, since this was probably also a machine for the builder's own use. Building of injection moulding machines for a company's own production was common up to almost 1960, which explains the large number of manufacturers (Table 1).

In the year of its founding (1926) Eckert & Ziegler presented the first machine produced in series, the famous EI (Fig. 4) and the larger EL, both in a horizontal design. This represents the birth of the so-called horizontal machine, with the injection unit on the right and the clamping unit on the left. The small hand-op-

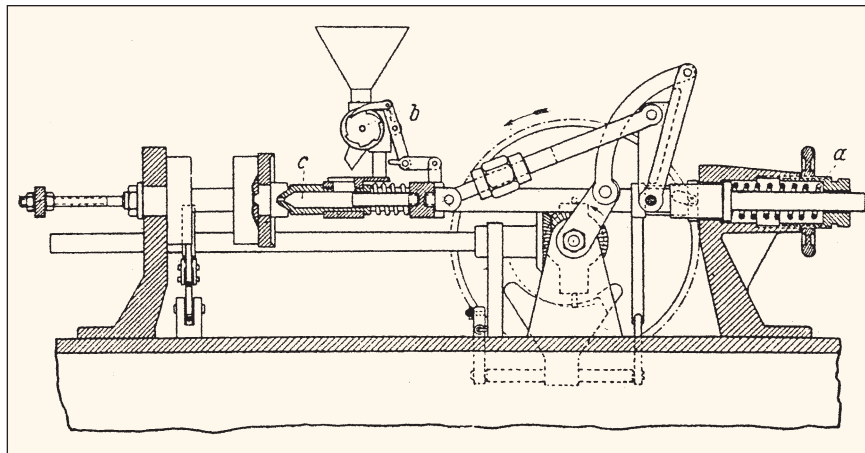


Fig. 6. Automatic injection moulding machine of Eckert & Ziegler from 1927; German Patent DRP 469994 [2] with an electric motor for the drive; a: overload spring, b: metering device, c: injection plunger

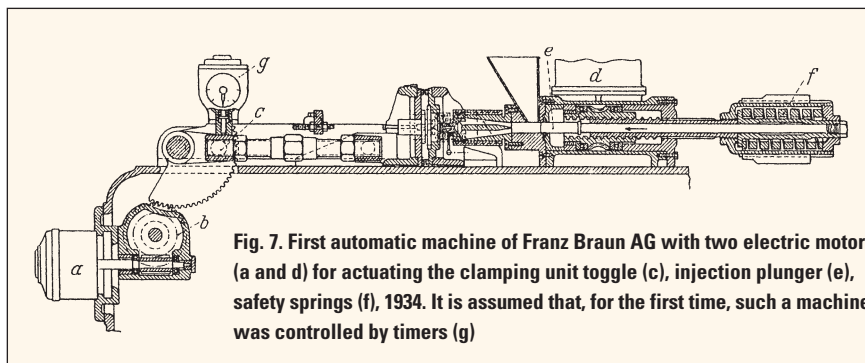


Fig. 7. First automatic machine of Franz Braun AG with two electric motors (a and d) for actuating the clamping unit toggle (c), injection plunger (e), safety springs (f), 1934. It is assumed that, for the first time, such a machine was controlled by timers (g)

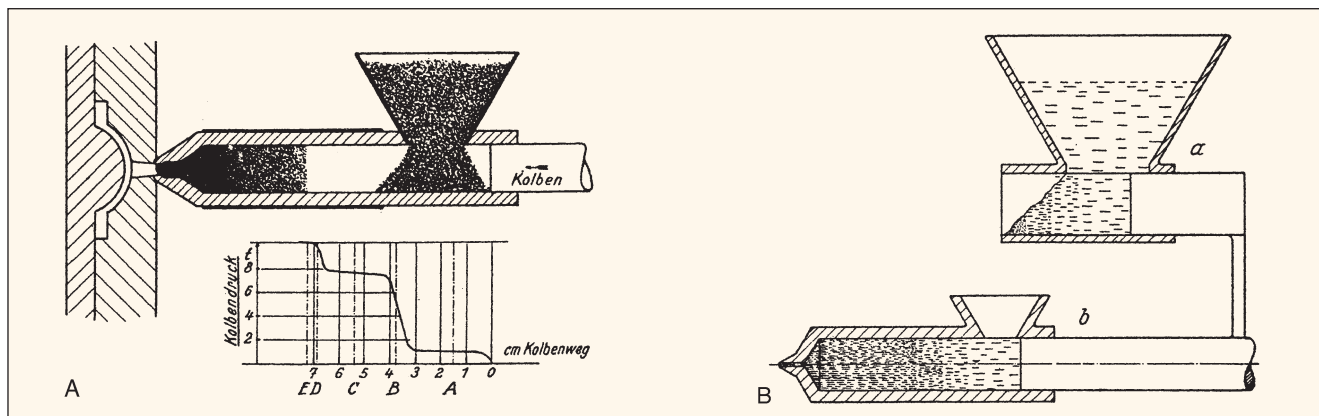


Fig. 8. Plunger injection unit with and without material-metering plunger; A: direct filling, B: metering by plunger.

Kolben = Plunger, Kolbenweg = Plunger stroke, Kolbendruck = Plunger pressure

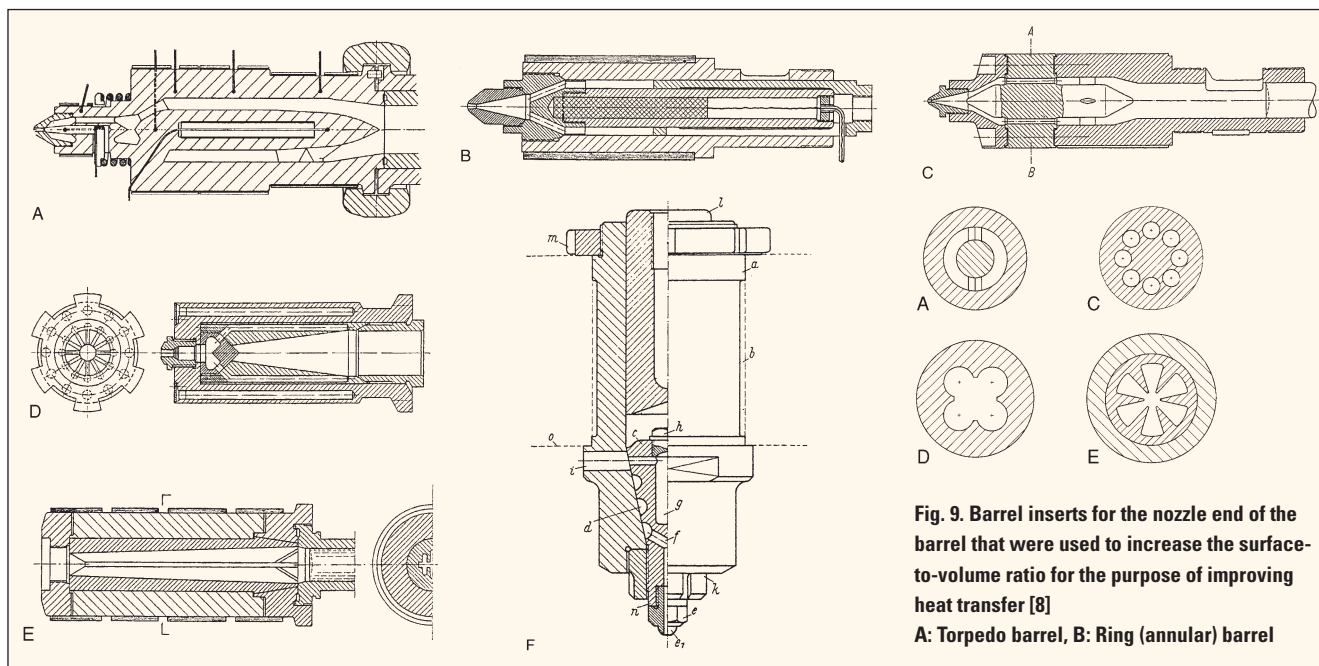


Fig. 9. Barrel inserts for the nozzle end of the barrel that were used to increase the surface-to-volume ratio for the purpose of improving heat transfer [8]

A: Torpedo barrel, B: Ring (annular) barrel

erated machine was capable of shot weights of up to 10 g. A toggle closed the mould with the aid of springs and then actuated the injection plunger with a continuation of the stroke. The EL machine, with a shot weight of up to 50 g, also had a hand-operated toggle for closing the mould, which was then clamped by pressing the nozzle against it. Injection was accomplished with the aid of a compressed-air cylinder. By 1944, 600 of these machines had been built.

While the EI machine had a shot weight of only 10 g, it was precisely the low shot weight that was key to its success. Since injection moulding was new to industrial practice, primarily very small parts were produced. In addition, this machine was especially favoured as a laboratory machine for development projects. An improved version, the EI V, had two hand levers, one for closing the mould

and one for injection. It was operated in testing laboratories until 1970.

In 1932, the Franz Braun Company under the management of H. Gastrow built the famous 'Isomats' in the then-impressive quantity of about 1000 units. The E and EL Series machines from Eckert & Ziegler and the Isomats from Franz Braun determined the course of injection moulding throughout the world for some time, especially via licensing in the USA. For instance, one can read the following sentence in [11], which reflects the good reputation that German machines still enjoy today: "In the early 1920s, Eckert & Ziegler built the first satisfactorily operating injection moulding machines. These early German machines were critical for the successful introduction of injection moulding to the United States". Injection moulding machines with shot weights of up to 500 g were developed by 1945. Looking at the Model EK IV 30 ma-

chine of Eckert & Ziegler and the Isomats of Franz Braun from 1932, their relevance quickly becomes apparent. These machines were electromechanical ("fully electric") in operation. An electric motor closed the clamping unit via a planetary gear and a simple toggle mechanism. Completion of the closing motion was signaled by an electrical contact, which then initiated injection. Another electric motor advanced the injection plunger either with the aid of a toggle (EK IV) or a spindle (Isomat). For safety reasons, a spring pack was also incorporated. A so-called maximum relay ended the stroke of the injection plunger. Two electrical timers controlled the duration of holding pressure (second-stage pressure) and cooling. Compared to today's "fully electric" machines, only the rotating screw, which was not yet present, was missing. The shot weight of the first Isomats was between 30 and 35 g. At that time and up

until about 1963, machines with direct electric drive and toggle conversion of the rotational motion of the motor were quite common.

Fully automatic metering of material, i.e. volumetric metering by means of a metering cylinder operating in conjunction with the injection plunger, was already employed early on. Thus, as early as 1927, the road to automatically operating machines was open at Eckert & Ziegler. They became more and more common, however, only after about 1936. From today's vantage point, this is hard to understand, since automatic machines were available even before 1930. One of the reasons for the slow introduction of automatic injection moulding was that initially only small quantities were produced. It did not pay to replace manual labour with expensive automatic machines.

The automatically operating machines of 1926, 1927 and 1934 already exhibited features of today's modern electro-mechanical (fully electric) injection moulding machines (Figs. 5, 6, 7 and 8).

Information

Important companies that are mentioned here, but no longer exist as such:

- Ankerwerk, Gebr. Goller: today, Demag Plastics Group, Schwaig
- Fa. Braun, Zerbst was completely dismantled in 1945,
- Eckert & Ziegler, Weißenburg: since 1968, Krauss-Maffei, Munich

Initially, only a single drive motor was needed, since for many years the closing and clamping forces were generated by pressing the nozzle against the mould. In the machine shown in Fig. 7, the closing toggle and injection plunger are operated independently of one another. The spring pack (f) prevents sudden overloading of the motor and provides holding pressure. Gear segment mechanisms were employed thereafter for many years, e.g. by Battenfeld.

Between 1926 and 1945, Eckert & Ziegler filed more than 60 patents relat-

ed to injection moulding machines and was the most important manufacturer worldwide. Even Braun AG submitted more than 35 patent applications. Eckert & Ziegler was later incorporated into Krauss-Maffei AG. Franz Braun in Zerbst was completely dismantled in 1945, restarted as Zerbster Maschinenbauanstalt, then as WMW and finally stopped building injection moulding machines. After the complete disintegration of a previously strong presence in Eastern Germany and without state support, the injection moulding machine building industry in the GDR barely survived up to 1965 [1].

A few technical solutions are presented here in brief, because some are reappearing today.

- Direct electromechanical mould closing and clamping by means of electric motor in conjunction with an attached bevel gear transmission and four tiebars with threaded spindles, introduced in 1939 at the Leipzig Trade Fair by Franz Braun AG;

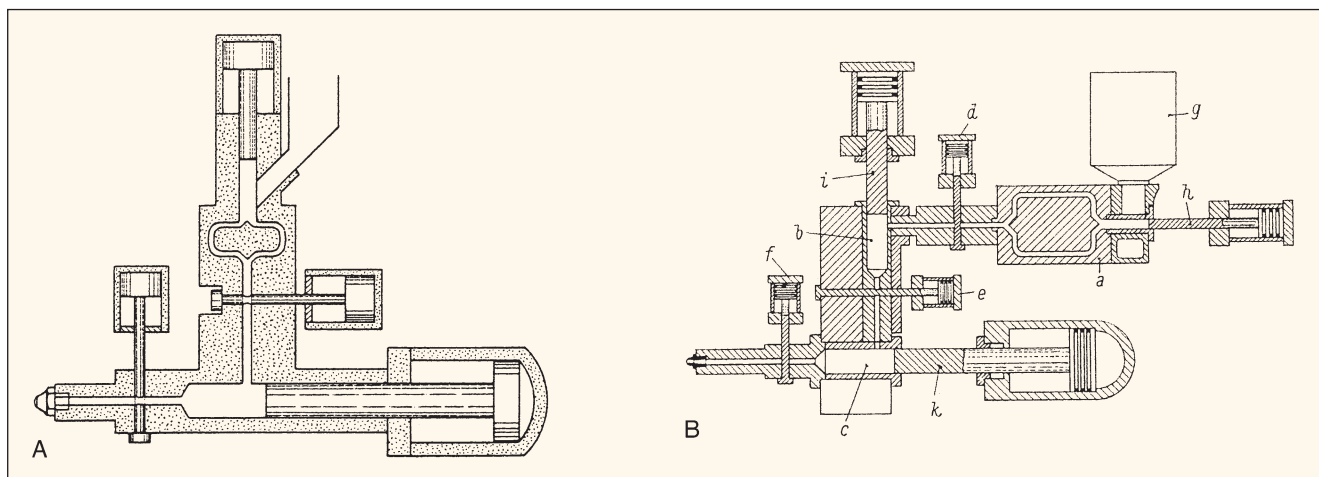


Fig. 10. Complicated designs for preplasticising with plunger (A) and in-line arrangement (B) [8]

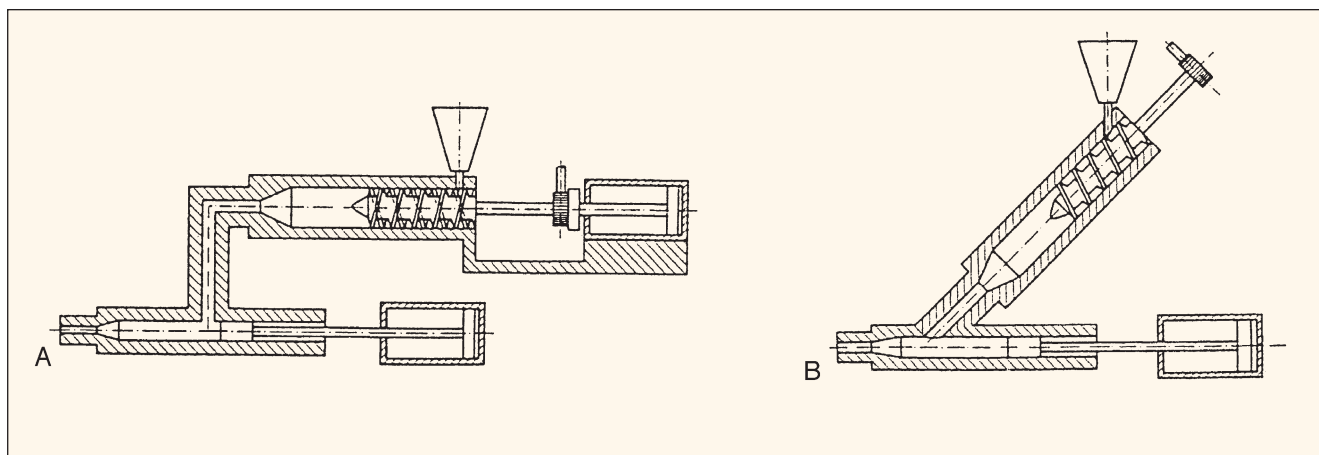


Fig. 11. Screw preplasticising

A: side-mounted screw unit, Jackson & Church, USA, see also German Patent DRP 693035, 1938, B: Injection plunger in the hollow screw [8]

- Preplasticiser unit as mixer, Franz Braun AG;
- Injection via toggle mechanism, operated by a compressed-air cylinder, Franz Braun AG;
- Vertical design with injection unit above and clamping unit below, Franz Braun AG;
- Preplasticising with reciprocating screw, 1940, A. Henry, USA;
- Toggle mechanism with spindle actuation, Eckert & Ziegler, 1939, DRP 128 740;
- Toggle mechanism with gear rack, Eckert & Ziegler, 1941, Italy, Pat. 391 720

Between 1943 and 1953, development of this technology was interrupted.

Preplasticising and Plunger Injection (1950 to 1956)

After 1950, industry recognised the great importance of the injection moulding process for production of housing of all kinds. Plunger machines were built with shot weights of up to 6000 g (Becker & van Hüllen, Krefeld), 9960 g (Rochester, USA) and 10 000 g (Triulzi, Italy). Today, these shot weights are unimaginable for plunger machines. Usually, however, polyethylene (PE) was processed to produce large containers. The classical injection unit consisted of a smooth cylinder (barrel) with a tightly fitting plunger (Figs. 8 A and B).

Heater bands were employed quite early to provide external heat. The temperature was often controlled with the aid of slide potentiometers connected in series. Because of the poor thermal conductivity of the block of plastic in the barrel, there was a constant battle with the mixture of degraded resin in the vicinity of the barrel wall and unmelted resin in the interior. Thus, starting with shot weights of 50 g and upwards, the large cross-section of the barrel was divided into several smaller ones in order to facilitate the introduction of heat into the poorly conducting plastic. In the early 1930s, this led to the torpedo barrel (Fig. 9A), ring barrel (Fig. 9B), also tubular barrel, ribbed tubular barrel, ribbed barrel and barrel with helical channels. Very thin-walled mixing barrels were also developed.

Preplasticiser units improved the melting performance. Figs. 10A and B show two preplasticiser units as an interesting historical note. These rather complicated melting units not only reduced cycle times considerably, but also permitted a doubling or tripling of the shot weight of a machine (Figs. 10 + 11).

About 1940, A. Henry used a reciprocating screw for preplasticising and the screw of today was born. Screw preplasticising was employed for many years, even twin-screw units. There was also a solution with reciprocating twin screws (Fig. 12) [1].

The Development of Screw Injection

With the introduction of the reciprocating screw that also functioned as a plunger, the year 1956 represents a special date – for machine builders as well

Table 2. Developmental history of screws and injection

1870	Invention of "celluloid"
1872	Injection machine of J. W. Hyatt, USA
1905	Vorraber, first reciprocating injection screw, German Patent 180007
1905	Cellit-Patent von Farbenfabriken vorm. Friedrich Bayer & Co.
1908	A. Eichengrün invents the "acetyl-cellulose resin"
1919	Production of acetyl-cellulose as injection moulding compound, Trade name: Trolit W, from Dynamit Nobel AG
1919	A. Eichengrün, The Injection Moulding Process, DRP 395084
1920	Dynamit Nobel, nonflammable nitrocellulose "Trolit F"
1920	H. Staudinger, BASF, invents polystyrene
1921	First hand-operated injection moulding machine of Buchholz
1922/23	Eckert Bros., Nürnberg, First vertical hand-operated injection moulding machine with gear rack drive for the injection plunger
1924	Eckert Bros., Nürnberg, First machine with compressed air-operated injection plunger, with liquid temperature control for processing "...celluloid and casein..."
1925	First hydraulic injection moulding machine; DRP 470 104
1926	First series-produced injection moulding machine, Eckert & Ziegler
1926	K. Welscher, First automatically operating injection moulding machine with fully electric drive; DRP 468 754
1927	Barrel with circulating melt "...through which the melt is mixed well and the risk of burning is reduced", Eckert & Ziegler
1927	First automatic injection moulding machine, Eckert & Ziegler, with fully electric drive by means of one electric motor
1927	Low-pressure injection moulding machine with twin-screw barrel and intrusion capability as well as shutoff nozzle with stroke control; DRP 467 753, Eckert & Ziegler
1930	Electrically heating of the barrel; Franz Braun
1930	Large-scale production of PS at BASF
1933	Series production of an injection moulding machine, called the "Isomat", Franz Braun, Zerst, by Gastrow, with fully electric drive
1933	Braibanti Bros.: Screws as a so-called pressing element that operate without a non-return element, 'Noodle press'
1934	Leominster Tool Co Inc., USA, produces in series fully hydraulic machines on the basis of the Eckert & Ziegler machines, Franz Braun, (H. Gastrow) also files a patent application for an hydraulic drive, with a pump that reverses direction of rotation.
1934	Tennessee Eastman designs a machine for an impressive 230 g shot weight. Previously in the USA, only copying of the machines of Eckert & Ziegler and Franz Braun
1937	Introduction of central water-based hydraulics, Eckert & Ziegler
1938	Einführung der zentralen Wasserhydraulik Eckert & Ziegler
1938	Shutoff nozzle, Eckert & Ziegler
1938	Injection moulding of thermosets from so-called transfer pots
1938	Screw preplasticising, Eckert & Ziegler, DRP 693 035

as for the injection moulders concentrating on expansion. In 1956, H. Goller and H. Beck (also known as "Screw Beck") built the first reciprocating screw injection moulding machine in series in Nuremberg. They were initially shown to only a small group of technical experts.

In 1957, the machine was exhibited at the industrial trade fair in Hanover. H. Goller recorded in his diary „[...] the technical experts were extremely surprised that the rotating screw actually retracted as the material was being conveyed". The machine was also able to inject while the

screw was rotating. Beck himself was of the opinion that only in this way could adequate injection pressure be generated. This initial test machine turned out to be a long-term design (Fig. 13) and, contrary to initial expectations, was used in a three-shift operation for about 10 years, was repurchased and then presented to the German Museum in Munich. It is a "hybrid machine" with hydraulic main drive and an electric motor with gearbox for the screw drive.

A comparison by H. Goller dating from the year 1959 describes the stage of development that was attained (Fig. 14). These screw machines achieved about 2.5 times the plasticising capacity of plunger machines.

The Braibanti screw patent of 1933 for noodle factories was used, as was the Quillery patent in France for rubber processing. One should have expected that the step to processing of thermoplastics would have followed immediately. H. Beck filed his important patent in 1942. During the German occupation in the year 1942, the Quillery Company was visited. H. Beck was a member of this delegation. There is no record of whether the rotating and injecting screw was observed during this visit.

At a time when he had already thought of his reciprocating screw injection concept, Beck stated in a publication in 1951, "Another configuration employs the screw directly as the injection plunger, so that an especially simple design results [...]" It is not clear whether he meant the directly injecting (in-line) screw or the preplasticising screw. The step to today's plasticising and injection unit, although present from both a theoretical and a practical standpoint, had still not yet been made. It is difficult to understand that application of this concept did not occur immediately after 1942, or at least shortly after 1945. Between 1942 and 1956, H. Beck approached several injection moulding machine manufacturers with his idea, all unsuccessfully. If he had first gone to H. Goller, the screw machine would probably have been built several years earlier.

The whereabouts of a machine described in the English patent 633 568 dating from 1947 currently remain unknown. This patent describes a plasticising unit with a reciprocating screw, non-return valve and replaceable nozzle. The machine was operated by hand. If it had been equipped with either an electro-mechanical or hydraulic drive, it would surely have gone down in history as the

moulding machines

1939	Overmoulding of metal inserts, De Mattia & Tool Co., USA
1939	Industrial-scale production of "polyethylene"
1939	Quillery proposes a rotating and reciprocating screw for injection moulding of rubber (FP 855885)
1939	Application of transfer moulding for thermosetting resins
1943	Modern-day injection moulding screw; Patent application of Hans Beck
1947	Reciprocating screw injection moulding machine with non-return valve; English Patent 633 568
1949	Machines with fully electric drive, Battenfeld
1950	HPM, USA builds the first two-colour injection moulding machine with two injection units for production of two-colour typewriter keys
1951	Direct addition of colour on injection moulding machines mentioned (with preplasticising)
1952	Becksches Patent erteilt (Verzögerung wegen des 2. Weltkriegs)
1953	Erste Spritzgießmaschine mit Schneckenkolben (Doppelschnecken), Windsor
1956	Beck's patent issued (delay because of World War II) 1953 First injection moulding machine with reciprocating screw (two-screw design), Windsor
	H. Beck, Herbert Goller and Ernst Friedrich develop the first reciprocating screw injection moulding machine Shortly thereafter, Beck's patent must be withdrawn because of the Quillery patent. This experienced the same fate because of the Braibanti and Vorraber patents [23]
1956/1957	Hans Volland proposes the ring non-return valve
1959	Intrusion moulding machine, Ankerwerk, DBP 1 128 638
1957/1960	PVC screw, (Ankerwerk)
1961	Rubber processing with screws, (Ankerwerk)
1963	Thermoset processing with screws
1966	Venting (two-stage) screw
1967	Solid-state controls
1972	Integrated control system, presented by IKV, Aachen, and Krauss-Maffei, Munich
1973	Closed-loop control of injection moulding machines, Sycap system, Netstal
1974	Mixing screws, various manufacturers
1976	Microprocessor control for injection moulding machines
1984	Electromechanical drive (so-called "fully electric"); Fanuc
1987	Rediscovery of the power-splitting gear arrangement, Toshiba, (DE – PS 3 505 880)
1987	Barrier screw
1988	Three-tiebar machine for CD production
1989	Tiebarless injection moulding machine, Engel
1991	Barrier screws, double-flighted screws
1994	First industrial injection moulding machines for processing magnesium
1995	Injection moulding machines with clamping forces over 15 000 kN in two-platen design
1995	Direct compounding machine
1996	Turret (index platen) design (Husky); starting in 1996: numerous machines for special processes
1998	Novel micro-moulding machines

Fig. 12. Preplasticising with reciprocating screw of A. Henry, about 1940

Feststehende Platte = Stationary platen, Düse = Nozzle, Schneckenbefestigung = Screw attachment, Schneckengehäuse = Screw housing, Schnecke = Screw, Verschlusshahn = Shutoff valve, Trichter = Hopper, Fenster = Window, Arbeitsrichtung = Direction of motion, Wasseranschluß = Water connection, Spritzkolben = Injection plunger, Spritzzylinder = Injection cylinder

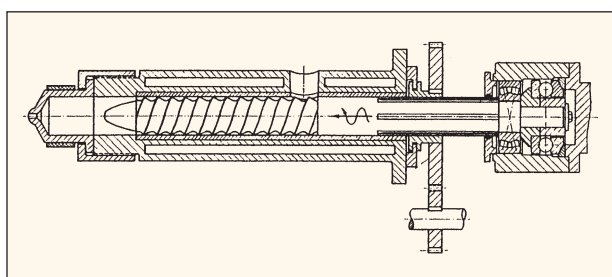
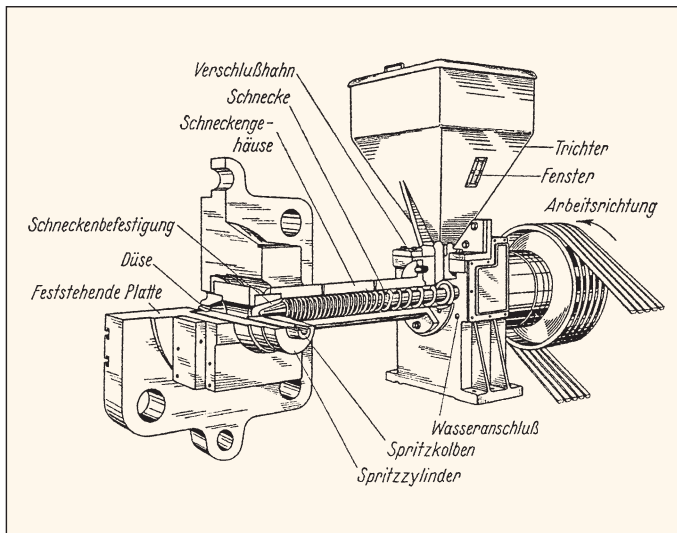


Fig. 13. Reciprocating screw unit according to the patent application of H. Beck, originally German Patent DRP 838310 "The essential step towards the future of injection moulding!" [8]

first reciprocating screw injection moulding machine.

The first screws in many machines were only 6 to 8D long. This dimension was based on experience with processing of polystyrene. When attempting to injection mould polyamide (nylon), at the latest, it became obvious that considerably long screws were needed. Screw technology was adopted immediately in Europe. Within only about 12 months, no plunger machines were available for purchase. Plunger machines with screw preplasticisers survived a few months longer. Due to their consistent use of reciprocating screw injection German injection mould-

ing machine manufacturers became the technology leaders throughout the world. Companies such as Ankerwerk Gebr. Goller, Eckert & Ziegler and Battenfeld, Meinerzhagen, were involved to a high degree from the very beginning. However, names such as A. Stübbe, Dr. Sommer, Arburg, J. Kraus and Nothelfer, along with a few other small suppliers, were also important in the machine sector.

The reaction of the Americans, who remained reserved for several years, is hard to understand. For instance, A.R. Morse wrote in 1961 „[...] Nevertheless, injection moulders are still rather inexperienced with moving screws. These are probably special machines (the screw machines) for limited applications, especially for thermally sensitive plastics, but not the universal machines that Americans expect". This hesitance, which lasted until about 1962, was ultimately extremely beneficial as regards the business opportunities of German machine suppliers in the USA.

H. Beck initially felt, and not unjustifiably, that a non-return valve was superfluous. In his reasoning, he explained very clearly that the feared reverse flow of melt back up through the hopper was func-

tionally impossible. Beck acknowledged, however, that a non-return function at the screw tip could be useful to compensate for the loss resulting from the compressibility of the melt. He also recognised the importance of back pressure. While the screw increased the size of the machine, and permitted an increase in shot weight to 30 kg and more, Goller recognized very early that it was now also possible to process successfully even difficult products such as rigid PVC and, later, even rubber and thermosets.

The "Autoplas single stage multi-screw pre-plasticiser unit" from Windsor dating from 1953, the description of which (with a few exceptions) sounds as modern as if it were written today, was not destined for success. It was too expensive (Fig. 15), the reason being the complex and costly design of the two screws and barrel. Nevertheless, for some time even after 1956, Windsor attempted with this design to slow the success of the single-screw machine. Additional important milestones are listed in [2, 4] and in Table 2.

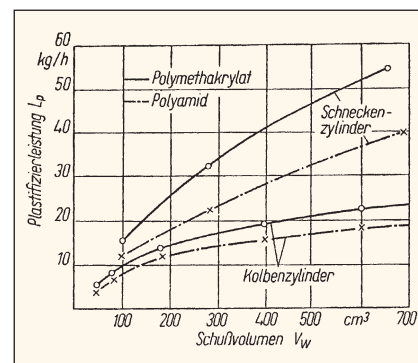


Fig. 14. Plasticising capacity for PMMA and PA in a plunger barrel and in a screw machine (original data from H. Goller [8])

Plastifizierleistung = Plasticising capacity, Polymethakrylat = Polymethylmethacrylate (PMMA), Polyamid = Polyamide (PA), Schnecken-zylinder = Screw barrel, Kolbenzylinder = Plunger barrel, Schußvolumen = Shot volume

A consideration of history shows that, especially in recent years, processes and machine components that were documented in earlier patents and ideas still reappear. The closing and clamping systems of earlier machines incorporate drives with spindles, gear racks and crank drives in conjunction with toggles or as direct actuating mechanisms in a variety of designs.

In the years of M. E. Laeis, H. Gastrow, H. Beck, H. Goller, G. Thilenius, H. Volland und G. Friedrich – between

! Note

This article is a revised version of the chapter "Geschichte des Spritzgießens" from the German book "Handbuch Spritzgießen" by F. Johannaber and W. Michaeli, Carl Hanser Verlag, Munich 2004



1940 and 1965 – these individuals were equally capable of dealing with the intellectual challenge of inventing the process sequence for injection moulding as well as manufacturing the material object required for its implementation. With increasing complexity, the commonly encountered division of labour (Taylorism) also took place in injection moulding. Injection moulders were divided into designers, hydraulic technicians, control technicians, application technicians, mouldmakers and the like. Understanding of the process was not always consistent and cooperation not always without friction. The information technology employed today, displayed on the screen at the machine



Fig. 16. Modern-day injection moulding machine (manufacturer: Engel)

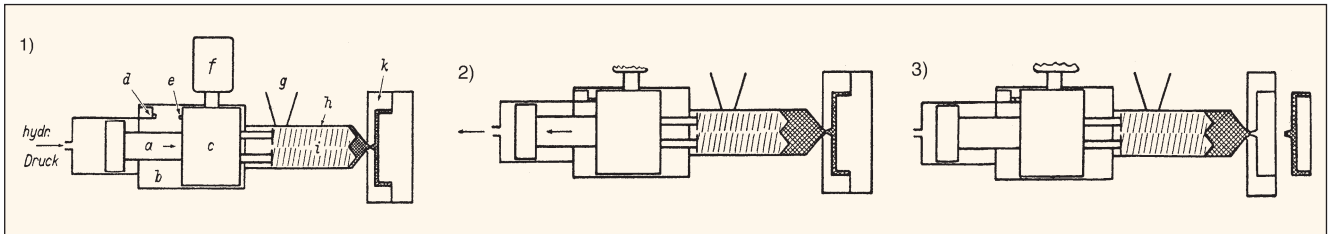


Fig. 15. First injection moulding machine with screw injection dating from 1953, manufacturer: R. H. Windsor Ltd., England;
a: hydraulic plunger, b: housing, c: gearbox case, d: limit switch for metering (recovery) stroke, e: positive stop, f: hydraulic screw drive motor, g: hopper, h: barrel, i: twin screws, k: mould
Phase 1: Injection and holding pressure, Phase 2: Recovery, Phase 3: Ejection. Hydr. Druck = hydraulic pressure

or at a central terminal, puts us once again in a position to reverse this process. The reintegration made possible by computers improves the generally accessible knowledge of the injection moulding process. The uncorrupted process data is clearly visible and accessible to everyone, from engineering to the machine operator. From external appearances, it is hard to believe that basically the same technology can be found in the machine from 1936 shown in Fig. 4 and under the guarding of the machine in Fig. 16.

In spite of the development undergone by injection moulding machinery, the technology underlying today's machines does not differ at all from that of the J. W. Hyatt injection machine dating from 1872. ■

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Additional extensive references in [1 and 8]