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NEW DESIGN SOLUTIONS OF FOUR-DIE FORGING DEVICES (FDFD) AND OPEN-DIE FORGING TECHNOLOGIES

Abstract

Operation of four-die forging devices (FDFD) under various industrial conditions on a variety of hydraulic presses differing in terms of design features and automation degree proved that in every particular case and with a view to particular production needs, an individual approach is required to select both the proper FDFD design and the proper forging technology. Presented in this paper are various design solutions of FDFDs and various forging technologies based on application of these specialized devices. The main selection criteria for proper device design and forging technology are: high production output, which should be significantly higher as compared to existing production technology output; improved metal quality and quality of products (in terms of dimensional accuracy and surface quality); cutback of the whole production cycle extent due to reduction of forging cycle, heating period and auxiliary operations duration, and higher good metal yield. The paper describes new FDFD design solutions and new technologies, which meet these criteria for solving various technological tasks, and it is also shown which changes to technological process can be eventually required to gain the maximum benefit from using the FDFD.

Keywords

Four-Die Forging, forging press, ingot, technology, design of devices

1. Introduction

Ongoing technology development, introduction of new machines, production processes and technologies is inextricably bound with development of new metal materials with quite special, sometimes unique properties. At the same time, production volumes of many commonly used and well-proven metals and alloys are not reducing and sometimes even increasing globally, especially when it appears possible to significantly improve their servicing properties. It is mostly applicable to metals and special alloys which are produced mainly by means of forging methods. In view of the large variety of materials and requirements applied to them, more new diverse technologies were recently developed to forge materials in FDFDs installed on hydraulic presses. Hydraulic forging presses are globally produced in relatively small quantities by specialized machine-building companies. However, due to a commonly very long service life of forging presses, hundreds and hundreds of forging presses are being now operated in the industry. To our knowledge, more than 160 forging presses are operated currently only in the EU countries. These presses from different producers and with different manufacturing dates differ also in the design concepts, their mechanization and automation degree and their wear extent. So, at the stage of a FDFD project development all these differences shall be strictly considered, since they are of crucial importance for selection of a design solution and a forging technology to meet particular customer needs.

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2. Four-die forging technologies

Development of forging technology starts with a detailed study of a customer's existing forging technology, or, in case of a new production startup, with a development of technical requirements for new production. Prior to a forging technology development, an optimized general forging production sequence shall be developed, including ingots heating, rough- and finish forging cycles performed on forging presses, re-heating cycles, cut-off or sawing operations, straightening jobs (if necessary) and heat treatment. The main element in this sequence is the technology of four-die forging in a FDFD. Sometimes upon results of this study customers come to a decision to change all their existing production sequence, for example: changing dimensions and shapes of initial ingots, changing ingots heating and forging technology, introducing different types of machines to cut forged products and even considerable upgrade of their existing forging presses.

FEM-based calculations proved that by means of forging operations performed in FDFD it is possible to reach a several times higher deformation ratio at each single pass if compared to conventional forging between two dies. With this forging method a workpiece does not tend to crush under the applied forging loads, and cracks do not appear on it. Due to a specially developed dies movement schedule and reductions performed at high deformation ratios a significantly higher metal quality is achieved as compared to any other existing forging technologies. The whole technology of ingots (billets) forging in a FDFD can be conditionally divided into two steps: a rough forging step and a finish forging step.

At initial stage of FDFD forging technologies introduction with our first customers, workpiece reductions were performed according to a forging schedule without metal spreading between the dies (Fig. 1 a,b). This forging method involves workpiece turning after each pass at 45° around its long axis in the same circumferential direction in order to provide a required deformation treatment of entire workpiece surface starting from the second pass.

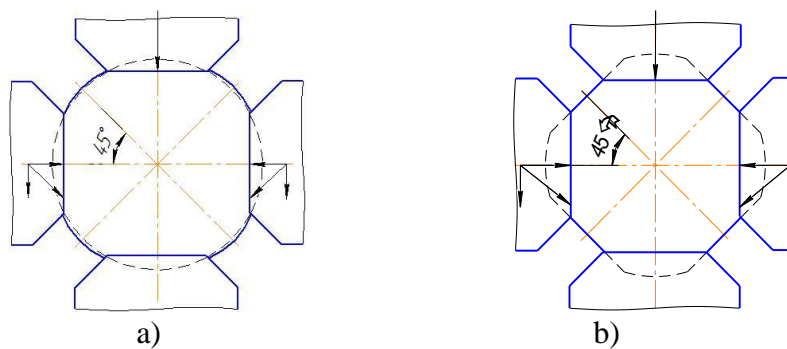


Fig.1 a,b. Reduction schedule for a workpiece of round cross-section without metal spreading between the dies.

Further we have developed a more efficient forging schedule, which can be employed in a FDFD with higher deformation ratios (Fig.2 a,b). This technology allows a more intensive deformation treatment of ingot cast structure due to higher single reductions and metal spreading between the dies [1].

This forging schedule results in more intensive supplementary shear strains in the workpiece area being forged. After the workpiece is turned at 45° , the material spread between the dies is pressed again into the workpiece, thus inducing shear strains across the total cross-sectional area of the workpiece. Besides, all the reductions performed during every single forging pass are acting so that the cross-section of the forged part is permanently displaced in relation to

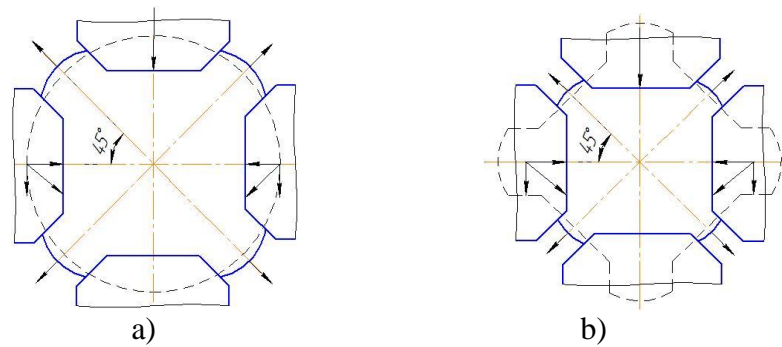


Fig.2 a,b. Reduction schedule for a workpiece of round cross-section with metal spreading between the dies.

the initial workpiece cross section in one and the same circumferential direction (Fig.3). Displacement of the workpiece cross-section in circumferential direction and intensive metal volumes displacement caused by top- and lateral dies pressure induce a twisting effect to the metal structure which results in improved metal quality.

The forging schedules described above were successfully implemented in production practice on many forging presses. The authors of the paper have also developed another FDFD forging technology involving twisting of metal macrostructure. Upon the results of industrial trials it was found that the combination of shear strains in the material resulting from the workpiece reduction between the dies and shear strains resulting from the workpiece section-by-section turning performed by manipulators provides a considerable improvement of metal quality.

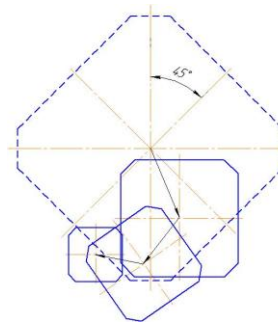


Fig.3. Reduction schedule for a workpiece of round cross-section involving intensive shear strain.

Moreover, a finer grain metal structure achieved owing to such forging treatment contributes as well to the higher metal quality. According to this method, shear forces in a workpiece are generated by means of simultaneous turning of two sections of a workpiece clamped with two manipulators gripping heads in opposite- or in one and the same directions. This technique serves to treat effectively the cast structure of metal and to obtain dense, fine-grained macrostructure of metal across the total workpiece cross-section with reduction ratios below 2:1. With the forging schedules involving supplementary shear strains it is possible to relatively easily maintain the workpiece material temperature within the required forging temperature range due to deformation heating of the area. In this case a FDFD shall preferably be used in automatic forging machinery systems. In consideration thereof, the authors have developed a special FDFD forging technology which makes it possible to maintain required metal temperature throughout the total forging cycle by means of respective deformation modes changing. In this forging mode heat losses resulting from heat transfer from the workpiece to the forging dies and also into the ambient air are compensated by the means of changing the volume of metal being formed at deformation site at each single reduction or by means of changing the reductions frequency. This method involves permanent workpiece surface temperature control during the forging cycle and, upon results of temperature measurement, respective correction of metal volume at deformation site prior to next

reduction or reductions frequency correction. This method can be employed both in manual operation mode of the press and in automatic forging cycles controlled by a computer system. Industrial trials performed on 5, 20 and 25 MN presses proved that such FDFD forging schedules provide conditions approaching to the isothermal ones. The authors have further developed new finishing technologies to be employed in FDFDs and also special finishing forging tools for this purpose. In one of these technologies forging dies with concave working surfaces are used in such a way that with the dies closed a cylinder-shaped space is formed between them. Both rough and finish forging operations are performed with the same dies having curved concave surfaces. In this case rough forging is performed at certain deformation ratio, and the following relation is maintained:

$$d_1/d_2 = 1,4 - 2,7; \quad (1)$$

where d_1 is an average diameter of an ingot or a billet;

d_2 is the diameter of circle inscribed in the space, which is formed with the dies closed.

Besides this, during finishing operation a certain relation between rough forged product diameter and diameter of finish forged product shall be maintained.

Presented in Table 1 are the examples of forged parts production by means of conventional forging technique (forging between two dies) and FDFD forging technique. Commonly used forging technology employed for the forging presses consists of two stages: first, a workpiece is forged between two flat dies, then the flat dies are removed and two channel dies are mounted on the press to accomplish finish forging of a product (technology No.1). When an ingot is forged between two dies it quickly cools down to the temperature below required forging temperature range, so after the 9th pass a workpiece reheating is required (Table 1). An ingot of 4300 kg is forged in 23 passes, and the total forging cycle according to conventional technology lasts 1195 seconds (excluding time loss for workpiece re-heating and dies changing).

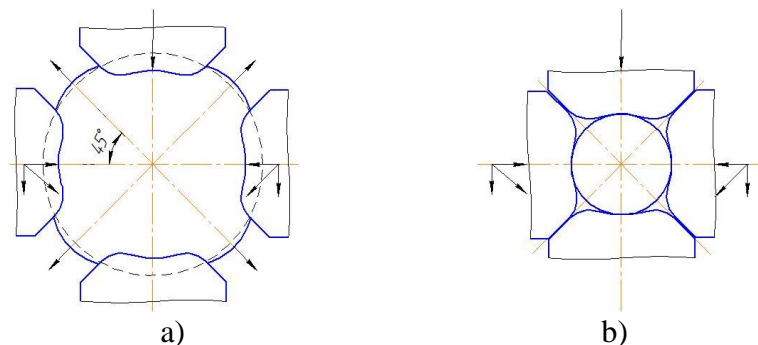


Fig.4 a, b. Schedule of workpiece reduction at rough forging (a) and at finish forging (b) performed in a FDFD with the dies having concave working surfaces.

When forging in a FDFD (technology No. 2, Table 1), 11 passes are required to forge the product, and the forging cycle duration is 587 seconds which means two-times reduction of work and time, if compared to two-dies forging technique. Moreover, with the FDFD technique no reheating of the workpiece as well as no dies changing is required to perform finish forging job, since the same set of dies having concave surfaces (Fig. 4 a,b) is used both for rough forging (1st to 9th passes) and for finish forging (10th and 11th passes). Presently many forged parts producers use forging units consisting of two channel dies with springs for finishing application. For example, 15 such forging units were used to make finishing job for

products in diameters from 180 mm to 500 mm at one of the companies producing alloyed steel forged parts. Only one FDFD adjusted for finishing operations with three sets of dies having concave surfaces could efficiently replace all these 15 units.

Table 1. Examples of technologies for making forgings with two dies (No. 1) and four dies in FDFD (No. 2).

No	Step	Tool type	Manipulator movement	Start Ø, mm	Final Ø, mm	Manipulator movement	Manipulator rotation (step), deg	Manipulator rotation (continuous)	Reheating	Temperature, °C	Time sec.
1	2	3	4	5	6	7	8	9	10	11	12
1	1	Flat	Trasl.	600	530	200	0	0		1240	15
	2	Flat	Trasl.	530	530	200	90	0			18
	3	Flat	Trasl.	550	470	240	90	0			17
	4	Flat	Trasl.	550	470	240	90	0			20
	5	Flat	Trasl.	490	400	240	90	0			25
	6	Flat	Trasl.	490	400	240	90	0			30
	7	Flat	Trasl.	420	350	240	90	0			34
	8	Flat	Trasl.	420	350	240	90	0			41
	9	Flat	Trasl.	370	300	240	90	0			44
	10	Flat	Trasl.	370	300	240	90	0	Yes		47
	11	Flat	Trasl.	320	278	240	90	0			51
	12	Flat	Trasl.	320	278	240	90	0			53
	13	Flat	Trasl.+Rot.	305	278	260	90	0			48
	14	Flat	Trasl.	395	335	260	0	0			52
	15	Flat	Trasl.	395	335	260	90	0			56
	16	Flat	Trasl.	345	278	260	90	0			58
	17	Flat	Trasl.	345	278	260	90	0			60
	18	Flat	Trasl.+Rot	300	278	260	90	0			45
	19	Flat	Trasl.+Rot	300	278	260	45	0			46
	20	Flat	Trasl.+Rot	300	278	260	90	0			46
	21	Round 290	Trasl.+Rot finish	300	278	50	0	45			114
	22	Round 290	Trasl.+Rot finish	283	278	50	0	40			114
	23	Round 290	Trasl.+Rot finish	283	278	35	0	35		890	160
Total										Σ 1195	

Table 1 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
2	1	FDFD	Trasl.	600	560	330	0	0		1240	18
	2	FDFD	Trasl.	560	520	380	45	0			18
	3	FDFD	Trasl.	520	490	290	45	0			23
	4	FDFD	Trasl.	490	450	300	45	0			27
	5	FDFD	Trasl.	450	420	280	45	0			32
	6	FDFD	Trasl.	420	360	250	45	0			44
	7	FDFD	Trasl.	360	340	300	45	0			42
	8	FDFD	Trasl.	340	285	260	45	0			66
	9	FDFD	Trasl.	340	285	370	45	0			44
	10	FDFD	Trasl.+Rot finish	285	275	50	0	45			114
	11	FDFD	Trasl.+Rot finish	285	275	35	0	35		900	159
Total										Σ 587	

A FDFD used in this case is rather a compact-size device and its price is considerably lower than that of 15 spring-type forging units consisting of two dies each.

3. New design solutions of FDFDs

The basic principle of all our FDFD design solutions is: the bottom die always stays stationary, while the top body of the device actuated by the press top cross-beam moves down together with the top die connected thereto; the lateral dies move not only towards each other but also downwards to the bottom die thus generating supplementary shear strains.

All FDFD depending upon their design and technological features can be conditionally divided into several groups.

Groups according to technological features:

- devices intended for rough forging operations;
- devices intended for finish forging operations;
- devices intended for rough forging and subsequent finish forging in one and the same FDFD;
- devices intended to produce forged parts of round and square cross-section;
- devices intended to produce forged parts of round, square and flat cross-section;
- devices intended to produce forged parts of specially shaped cross-section.

Groups according to design features:

- devices equipped with die cooling systems and without die cooling systems;
- devices equipped with metal slider bearings;
- devices equipped with force feed lubrication of slider bearings;
- devices equipped with self-lubricating slider bearings;
- devices with a feature of quick connection/disconnection system to change dies in intervals between forging operations;
- devices with a quick-change system to change all four dies simultaneously;
- devices equipped with a non-rigid quick connection system intended to connect a FDFD to the press top cross-beam or to the press top die using special mechanisms incorporated into the FDFD body;
- devices equipped with supplementary guiding columns;

- devices equipped with springs intended to open the device, with no FDFD connection to the press cross-beam;
- devices equipped with rigid quick connection system to connect a FDFD to the press cross-beam;
- devices equipped with mechanisms for adjustment of the distance between opposite dies before forging operation.

Today we've decided to avoid using force feed lubrication systems to supply lubricant to the slider bearings and to use more advanced solutions incorporating self-lubrication slider bearings which can be of different versions [2, 3]. As for the cooling systems, we use them very occasionally and only in the devices intended to forge large batches of carbon- and low-alloy steel products, for example, railway axles for locomotives and carriages.

To ensure an efficient FDFD die changing, a respective FDFD design solution and special die-changing technique were developed (Fig.5) [4, 5].

All four dies in such device are connected to their respective holders by means of special clamps. Also special grooves are made in the dies to receive the clamps. The clamps are designed such that they can be connected to and disconnected from the dies with the help of springs installed in the holes of die holders; besides this, when disconnected from the dies, the clamps can be held either on the die holders or on the tie rods coming through the holders. When it comes to die changing during a forging operation in a FDFD, the changing procedure is as follows:

First, a workpiece is removed from the device working zone. Then the dies are closed, and adjacent dies in pairs are rigidly connected with the help of U-shaped ties installed into the holes, which are made in lateral surfaces of the dies. Then the dies are disconnected from their holders and the holders are brought apart. The structure consisting of four interconnected dies rests on the bottom die.

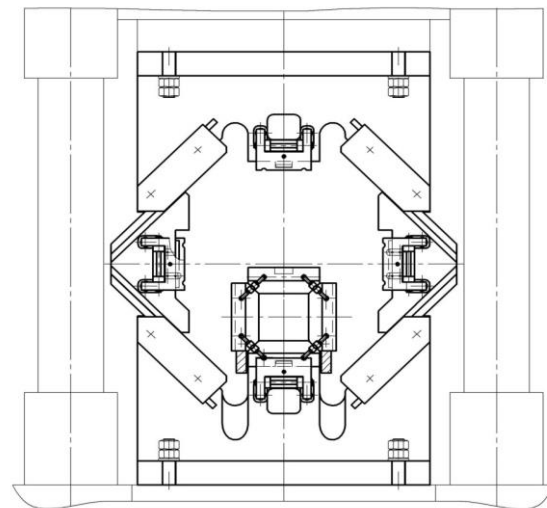


Fig.5. FDFD design solution providing for quick changing of all four dies simultaneously.

Then this structure is gripped with a lifting attachment, for example, using a manipulator and a mandrel in it, and brought out of the device working zone to a provided storage area where it is placed on respective support. A set of replacement dies shall be mounted in the FDFD in reverse order. It means that a set of interconnected dies is brought with the help of a mandrel clamped between the manipulator jaws into the device working zone. (Fig.6a).

And, finally, for the purpose of quick die changing the authors have developed a die connection system employing snap-type clamps (Fig.6b). Dies mounting procedure in this case is the following: a complete structure consisting of four dies shall be brought into the device working zone with the help of manipulator, then the device holders are brought together by means of the press top cross-beam so that the device holders press the dies bearing surfaces. Thus the snaps get actuated to grip the dies. Thereafter the U-shaped ties shall be taken out of the holes provided in the dies and a FDFD is ready for operation.

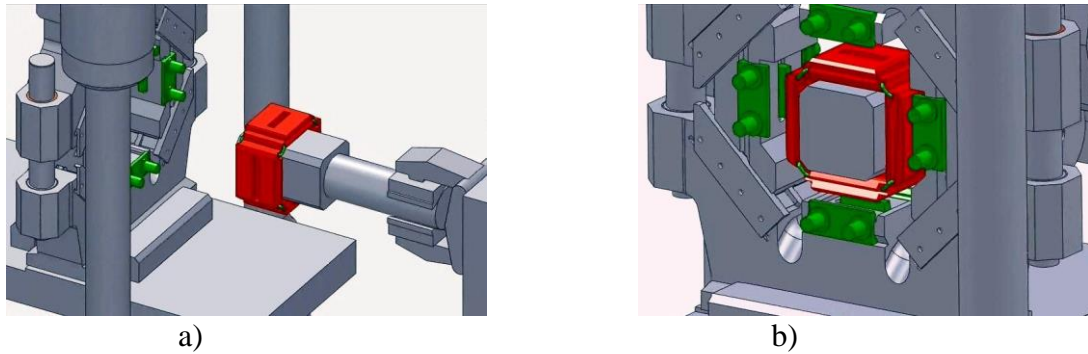


Fig.6 a,b. Schedule of dies mounting in a FDFD.

Top- and bottom tool connection mechanisms, as well as availability of a press tool table for quick die changing are of special importance for efficient operation of FDFD. Meant here are the mechanisms used to connect the FDFD top- and bottom bodies in the forging press.

Common practice is to connect a FDFD bottom body to the working table (or tool table) of a press, while a top body is connected to the press movable cross-beam with the help of a connection fixture used for conventional existing press tool. For the application cases when maximum cross-sectional size of products does not exceed 450mm, we use a FDFD device solution without device top body connection to the press movable cross beam. Corresponding springs are employed to bring the dies apart in this solution. FDFD equipped with springs can be much easier adapted to any existing press design and any forging technology. A device of such type can be brought into the press working zone within a few seconds and the same short time is required to take the device out from the press. Such time-saving solution is especially beneficial for applications involving forging not in a FDFD only, but sequentially between two dies as well.

However, development of a spring-type FDFD solution suitable to forge workpieces in diameters exceeding 450 mm is a very challenging task, since it appears rather difficult to find suppliers who can produce adequate springs capable of moving a device top body with a weight exceeding 2,5 Tons to a distance exceeding 300 mm.

In view of the said above, for the application at forging of the components with the cross-sectional size exceeding 450 mm we have developed a FDFD design solution including a system of non-rigid quick connection of the device to the press cross-beam or to the top die (Fig.7). Such a FDFD has respective catches designed to quickly connect the device to the press cross-beam or to the top die and to quickly disconnect it therefrom. A mechanism used to actuate the catches is driven by an electric motor.

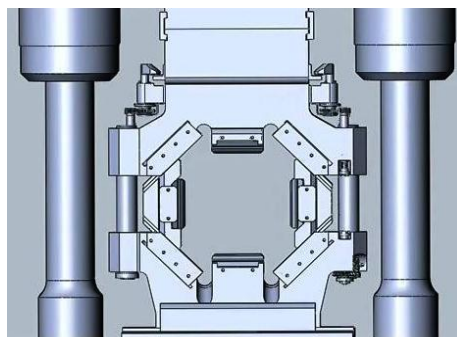


Fig.7. FDFD design solution with a system of non-rigid quick connection to the press top cross-beam.

Since the first experimental-industrial four-die forging device was built in 1990, a number of new FDFD design solutions was developed for the presses in capacities from 5MN to 120 MN and for a 1,25MN radial forging machine; all these devices were manufactured and put into industrial operation (Table 2) [6]. These devices are used to produce forged parts of carbon, middle-alloyed-, tool-, high-alloyed- and heat-resistant steels and alloys and also nonferrous metals and alloys.

Table 2. List of Manufacturing Plants where FDFDs are Installed.

Rated Press Force, MN	Year of Manufacture	Company (Country)	Qty of FDFD units	Lubrication system	Cooling system	Self-Lubricated Sliding Bearings
1	2	3	4	5	6	7
5	1990	UkrNIIspeetsstal (Ukraine)	1	No	No	No
1,25(RFM)	2000	NPP Rubin (Ukraine)	2	No	No	No
25	2003	Sidenor (Spain)	1	No	No	No
20	2005	OAO Tyazhpresmash (Russia)	1	Yes	Yes	No
25	2008		1	Yes	Yes	No
20	2006,2008	OAO VSMPO-Avisma (Russia)	2	No	Yes	Yes
25	2013		1	No	No	Yes
25	2006	OAO Bumash (Russia)	1	Yes	Yes	No
20	2008	SSM-Tyazhmash (Russia)	1	Yes	Yes	No
12	2010	OAO ChMZ (Russia)	1	No	No	No
120	2010	Tongyu Heavy Industry Co., Ltd. (China)	1	Yes	Yes	No
12.5	2013		1	Yes	Yes	No
16	2010	Qilu Special Steel Co.,(China)	1	Yes	Yes	No
20,30	2010	Baotou Iron & Steel Co.,(China)	2	Yes	Yes	No
45	2010	Seri Machinery Equipment Co., Ltd (China)	1	Yes	Yes	No
12	2011	Metal Manufacturing Company, Zhongshan (China)	1	Yes	Yes	No
25	2012	Chongqing instrument materials research institute (China)	1	Yes	Yes	No
10	2011	Kind & Co. Edelstaahlwerk (Germany)	1	Yes	Yes	No
30	2014	Villares Metals S.A.(Brazil)	1	No	No	Yes
30	2014	Acciaierie Valbruna S.P.A(Italy)	1	No	Yes	Yes

4. Conclusion

1. Selection of a forging technology and a FDFD design solution depends upon each particular forged parts production case. In order to obtain the best results from using the FDFD, it is necessary in each case to get detailed information about the existing forging technology and press structure.

2. New forging technologies for FDFD application were developed and introduced into industrial practice. It has been shown that a forging technology applied for FDFD equipped with one set of channel dies can be efficiently used not only for finishing operations, but also for rough ingot forging. For comparison purposes two existing forging technologies were studied: conventional technology of forging with two dies and forging technology for FDFD.
3. New FDFD design solutions and a quick die-change technology providing a possibility of quick change of all four dies simultaneously were developed and introduced into practice.
4. To provide a higher output, a new FDFD design solution employing a mechanism for the engagement of FDFD top body with a mating surface of the press cross-beam was developed. Such mechanism is arranged directly on the FDFD and is driven from an electric motor.
5. Information was provided herein about all industrial four-die forging devices which are currently installed at production sites in Ukraine, Russia, Spain, Germany, China, Italy and Brazil.

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