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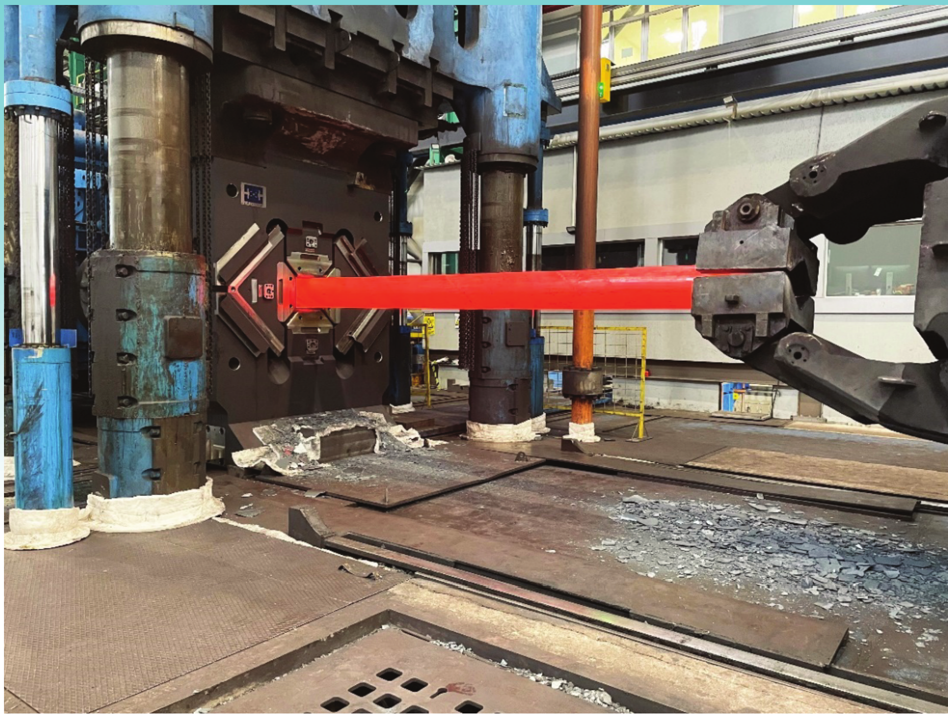


FOUR-DIE FORGING DEVICES (FDFD)

Four - die forging devices

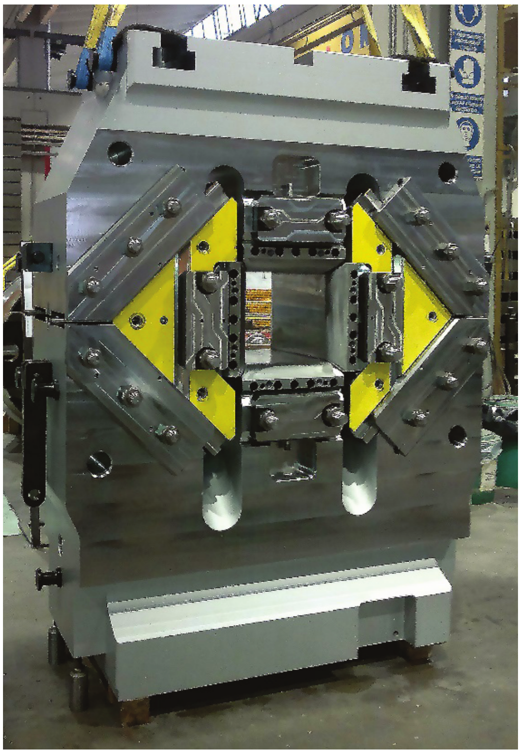
Four-die forging devices are designed to forge material on hydraulic forging presses from four sides simultaneously.

Four-die forging device (**FDFD**) is a unique forging tool which combines advantages both of radial forging method implemented on radial forging machine and conventional forging method using with two dies implemented on forging presses.

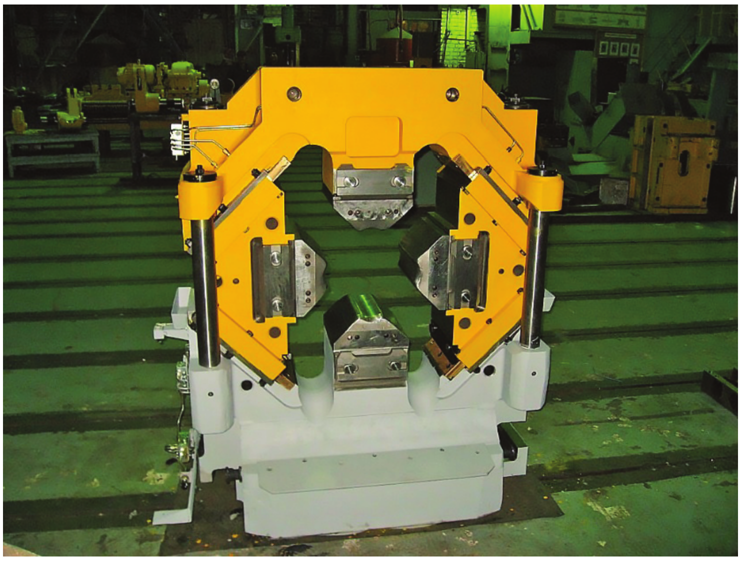
Four-die forging device is intended to be installed and fixed on the table of hydraulic forging presses with capacities from 2 to 150 MN just in place of conventional dies. It is designed to forge a workpiece with four dies simultaneously so that it generates supplementary shear strains in the material.

A number of various design options of the four-die device is possible according to various methods of device connection to the press :

- top body of the device connected to the press movable cross-beam or to the top die (a number of options);
- top body of the device is driven by means of a spring (no connection to the movable cross-beam)

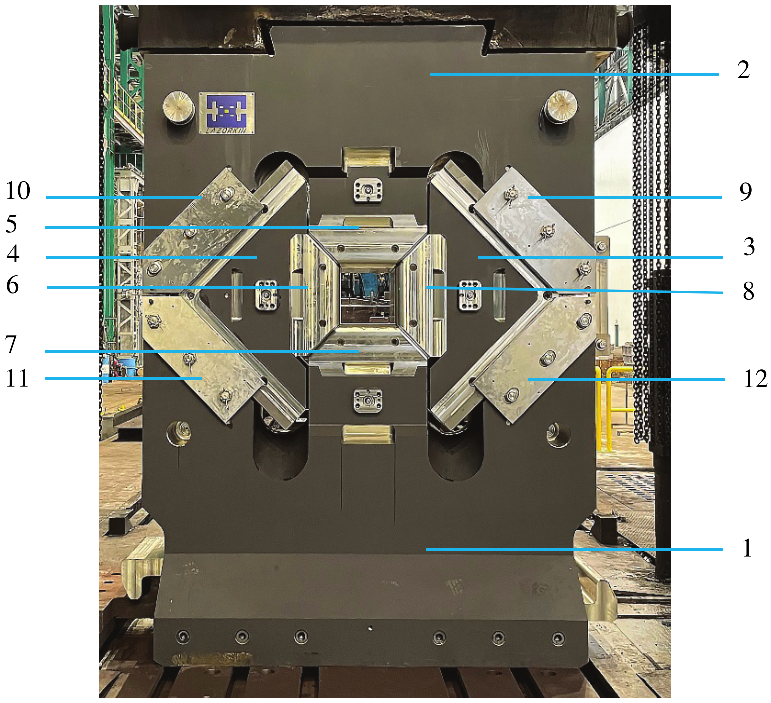


FDFD with fastening of the top body to the press 30 MN (Italy)



Four-die forging device with a spring employed to lift the top body for a 10MN press (Germany).

The FDFD consists of a bottom body 1 and top body 2, sliders 3 and 4, dies 5-8 and lateral guideways 9-12. The bottom body is rigidly fixed to the press table. Prior to operation the top body of the device shall be fixed to the press movable cross-beam. The die 8 is fixed to the bottom body and it does not move during the forging operation. The die 5 is fixed to the top body and during the forging operation it moves together with the top body. The dies 6 and 8 are fixed to the lateral sliders 3 and 4 respectively. As the press movable cross-beam moves upwards, the top body of the device goes upwards, too, and by means of eight lateral guideways 9-12 it brings apart the sliders 3 and 4 with the lateral dies 6 and 8 fixed thereto, thus opening the forging device working area. An ingot or a billet is fed by means of a manipulator into the opened working zone of the device and onto the bottom die 7. As the movable cross-beam moves downwards, the top body moves downwards, too, and via the inclined surfaces provided on the top and bottom bodies imparts motion to the sliders 3 and 4 carrying the dies 6 and 8. The dies 6 and 8 move not only towards each other; they also move at the same time downwards and towards the die 7 thus inducing supplementary shear strains in a workpiece being forged. A workpiece forged in such a device is reduced from four sides simultaneously.



To facilitate press operation using alternatively four-die device and conventional press tools and to eliminate the need to dismantle the top press die in order to connect the device to the movable cross-beam, we have developed a device where a spring is used to lift the top body and to respectively bring the dies apart.

The spring-type design is successfully used at a number of production plants. A special design of the lateral guideways serves not only to center align the top body relative to the bottom body and the sliders; it also serves to bring apart the sliders carrying the lateral dies fixed thereto without using any additional mechanisms. The advantages of this solution are: compact structure of the device and high operational reliability.

The benefits of the four-die forging device:

- 1,5 – 3 times higher output as compared to conventional two-die forging method commonly employed on presses.
- 8-15 per cent increased good metal yield
- 2 – 2,5 times reduced dimensional tolerances of the forged products and 1,5 times reduced allowances for finish surface machining which means 40 – 50 kg of metal saved per 1 ton of forged parts.
- 30 – 40 per cent reduced energy consumption at drawing operation.
- 25 – 30 per cent reduced gas consumption for metal heating due to elimination of reheating requirements.
- a better isotropy and improved physical/mechanical properties of forged metal.
- a wider range of steel grades which can be forged in the device and a wider range of finish product shapes.
- a possibility to forge low-ductile steel grades which can not be processed by means of conventional forging technologies.

General specifications of the forging operation:

Materials to be forged

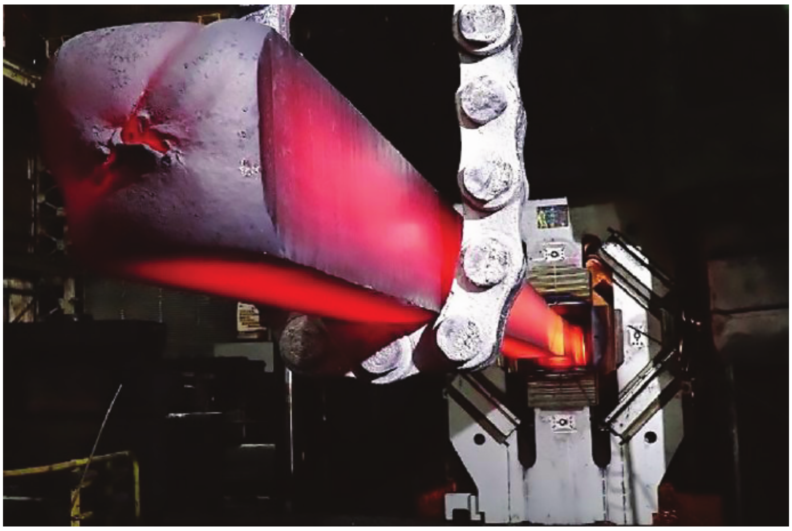
- All steel grades from carbon steels to high-alloy steels, including hard-to-deform steels
- Special alloys – high-temperature, heat-resistant, precision, etc.
- All ductile metals and alloys (ferrous and non-ferrous, e.g. titanium, zirconium, aluminum)

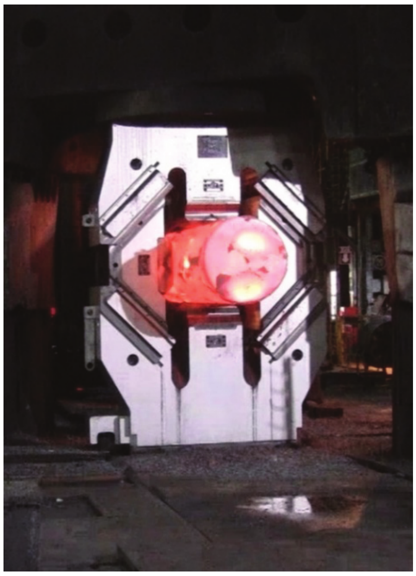
Shapes of forged parts

- Round, square, flat
- Bars of polygonal cross-section
- Stepped parts
- Hollow parts, also stepped ones

Shapes of initial components

- All types and shapes of ingots
- Solid and hollow billets
- Rolled stock





FDFD with dies for producing square forgings and with dies for producing round forgings on a 30 MN press (Japan)

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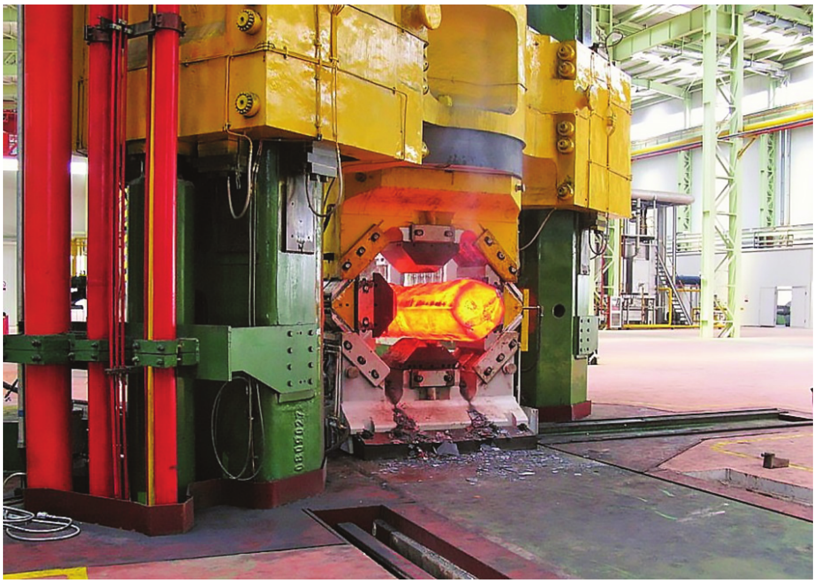
Presses which can be equipped with four-die forging devices

- All types of hydraulic forging presses in capacities from 2 to 150 MN
- All types of automatic forging plants



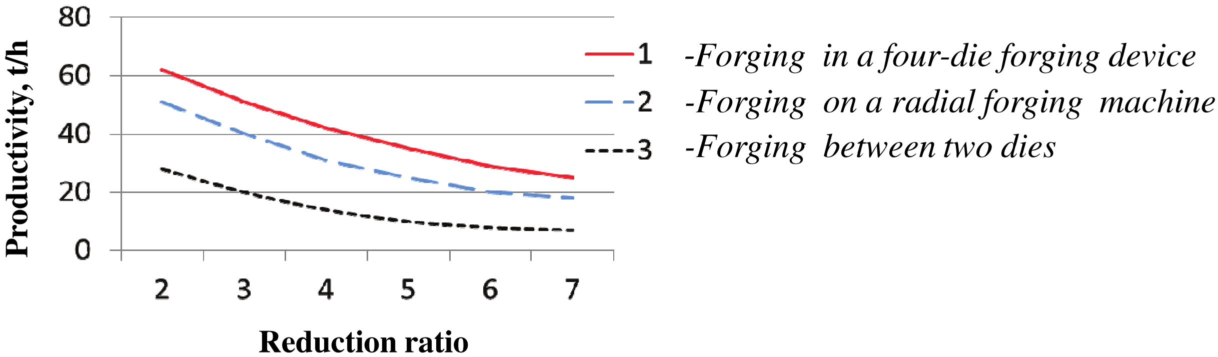

Application of a four-die forging device on a 25MN- and a 45MN presses (China)

Output

During two-die forging operation (conventional method) each single reduction results in considerable lateral spreading of metal which means a limitation of workpiece drawing in lengthwise direction. Thus, in order to obtain a forged part of required cross-section and length it becomes necessary to perform more additional workpiece turning and reduction cycles.

Due to the four-side reduction method, lateral metal spreading phenomenon is eliminated or at least minimized. Thus the number of workpiece turning and reduction cycles can be considerably reduced, which means a higher forging output.

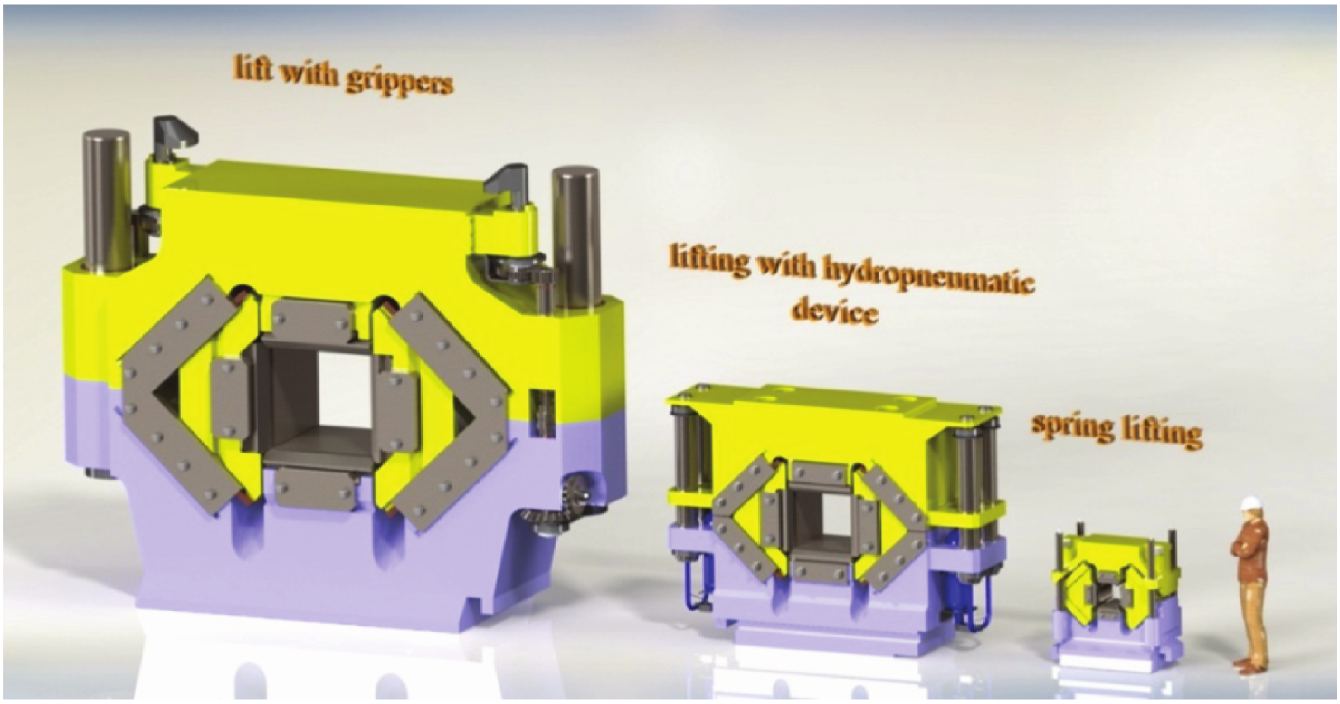
Due to the intensive deformation-heat generation a workpiece formed in a FDFD cools down much slower if compared to conventional two-die forging operation.
This phenomenon also contributes to reduction of reheating requirements and thus to a shorter production cycle duration.



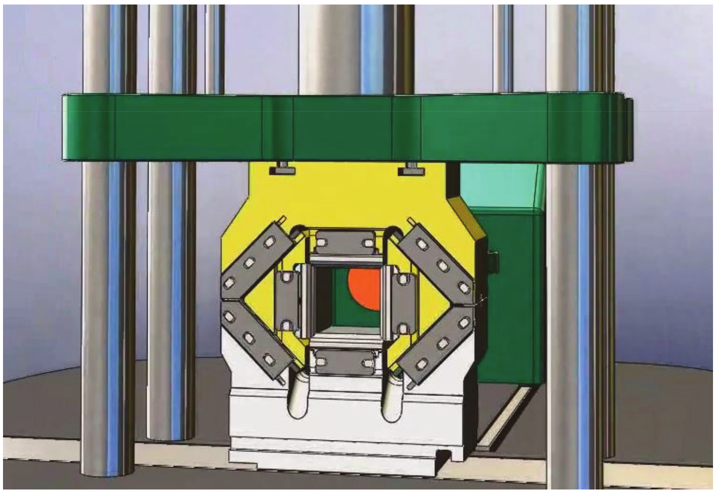
Variants of FDFD designs

FDFD designs can be different and depend on the design of the press, the size of the ingots (blanks), as well as the size and shape of the finished forgings.

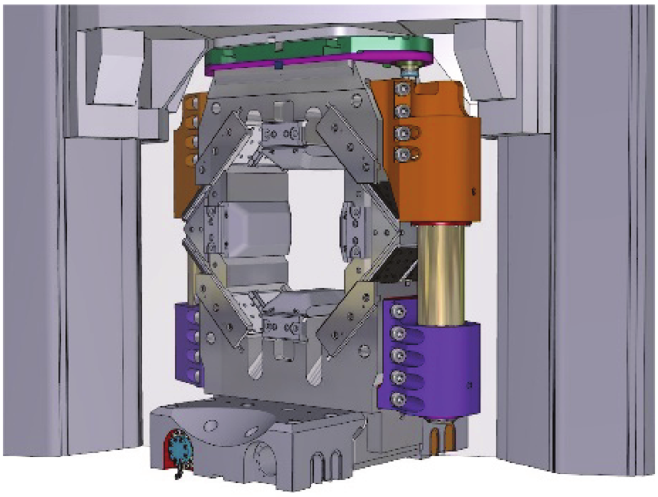
Lazorkin-Engineering offers the best option for a forging device, depending on the customer's technological process.



Variants of FDFD with special hooks, with hydropneumaticlifting mechanism and with spring lifting of moving parts

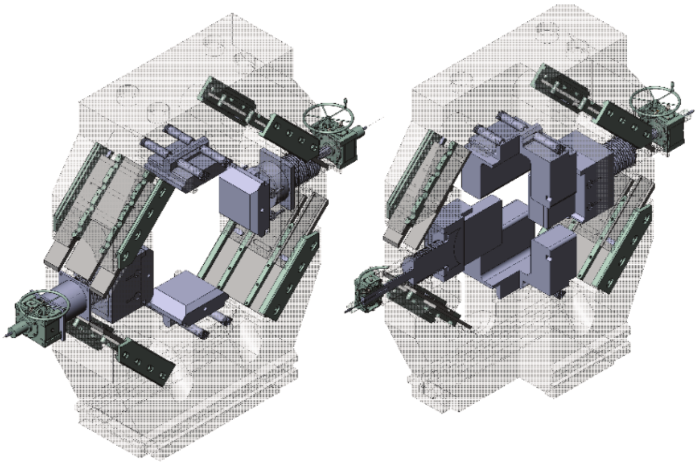


FDFD design with fastening directly to the press traverse plate



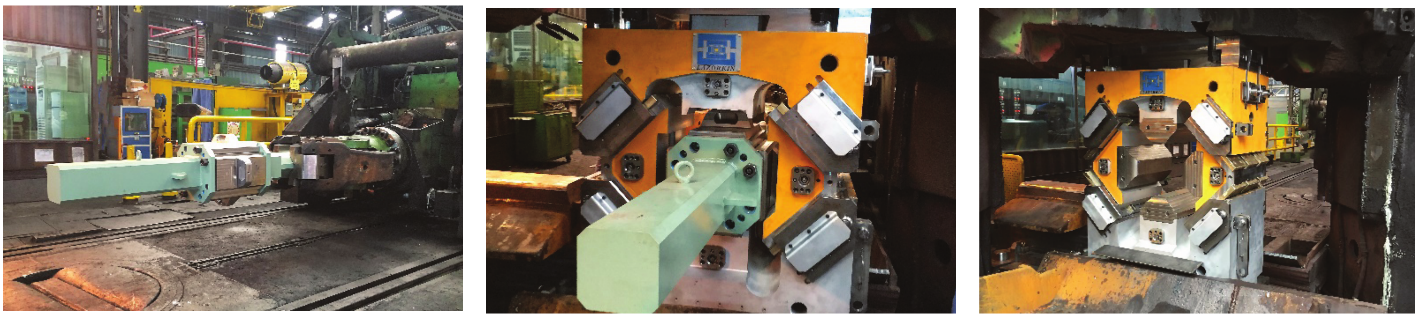
FDFD design reinforced with special guide columns for presses with large gaps in the guide bushings and a skew of the movable traverse

Another specialized solution of a four-die forging device was developed to produce flat products. Flats can be produced in a wide range of dimensions, and for this purpose the device includes a feature to adjust the device working area between the dies.



Four-die forging device for producing forgings of round, square and rectangular cross-section

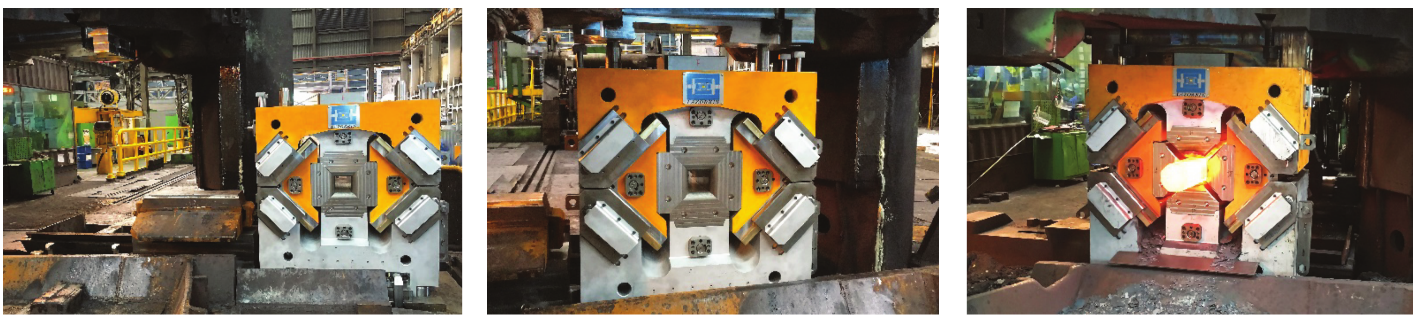
The quick change mechanism for the dies allows to change simultaneously all dies as a set within 10-15 minutes.



a) *b)* *c)*

Quick change of the dies on a 22 MN press (Korea)

The mount system, which attaches the FDFD directly to the top die of the press, allows to change the device within 3 minutes.



a) *b)* *c)*

Quick change of the four-die forging device on a 22 MN press (Korea)

Metal quality

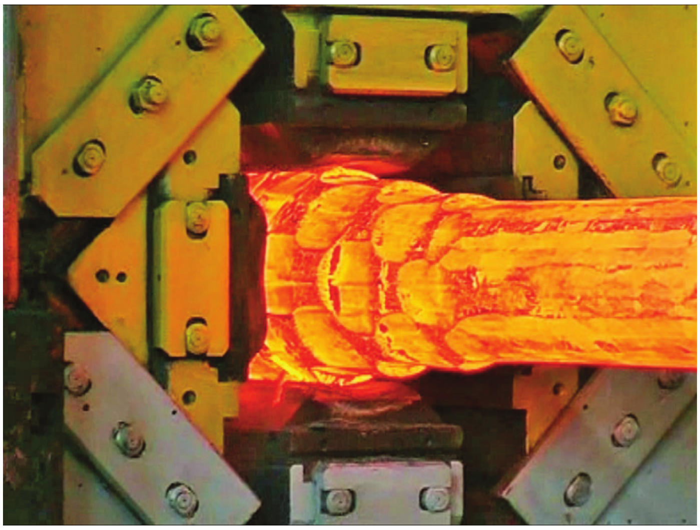
Four-side reduction schedule implemented in a four-die forging device generates compressive stresses across the workpiece cross-section which makes it possible to successfully forge in a four-die forging device even low-ductile and hardly deformable steels and alloys. In this aspect the forging process in a four-die device looks similar to the radial forging process implemented on the radial forging machines (RFM).

Moreover, forging operation performed in a FDFD contributes to a uniform deformation treatment of cast metal structure across the total cross-sectional area of a workpiece.

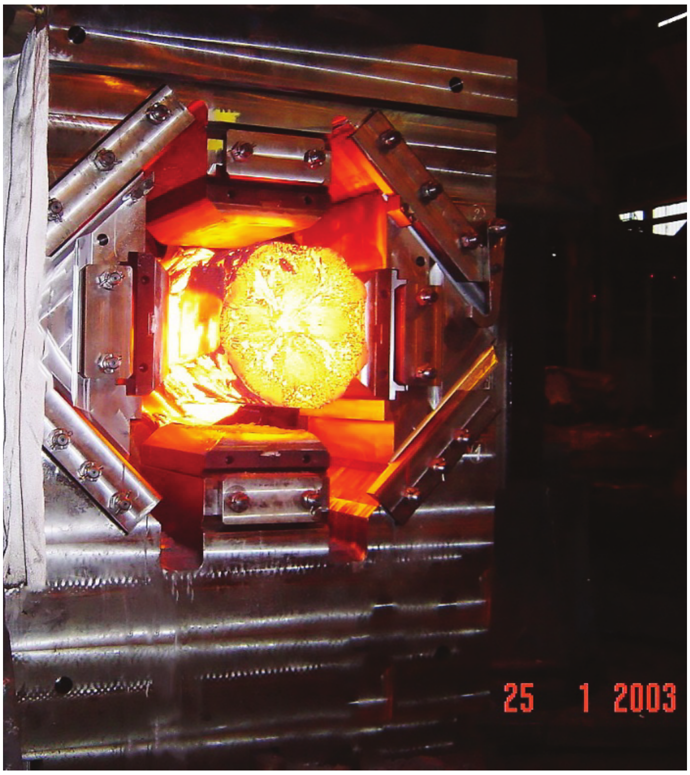
While the dies in a radial forging machine move in radial direction only, the dies in a four-die forging device make a combined movement in radial and tangential directions. It serves to induce complimentary shear strains in the total cross-sectional area of a workpiece being forged.

Due to this benefit and also due to the larger single reductions a considerably deep deformation treatment of cast metal structure is obtained.

When forged in FDFD, the products made of variety of structural-, alloyed-, tool- and stainless steel grades, as well as precision-, high temperature- and heat resistant steels appear to be free from porosity defects, and the metal quality is much higher than that obtained on a radial forging machine.



Four-die forging device on a 25 MN press



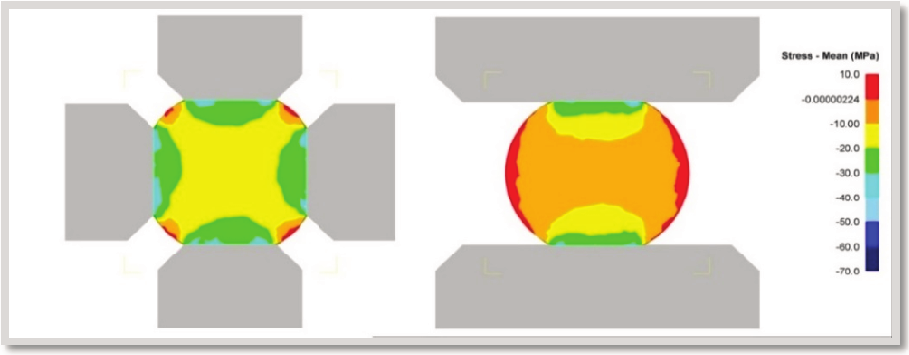
Four-die forging device on a 25 MN press (Spain)

Accuracy of forged parts

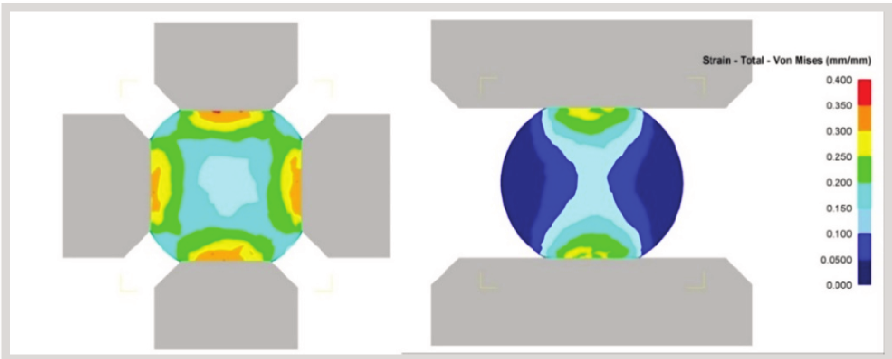
Forging in FDFD makes it possible to obtain forgings of various sizes with accuracy approaching blanks obtained on rolling mills.

Finished forgings obtained in FDFD

Technology



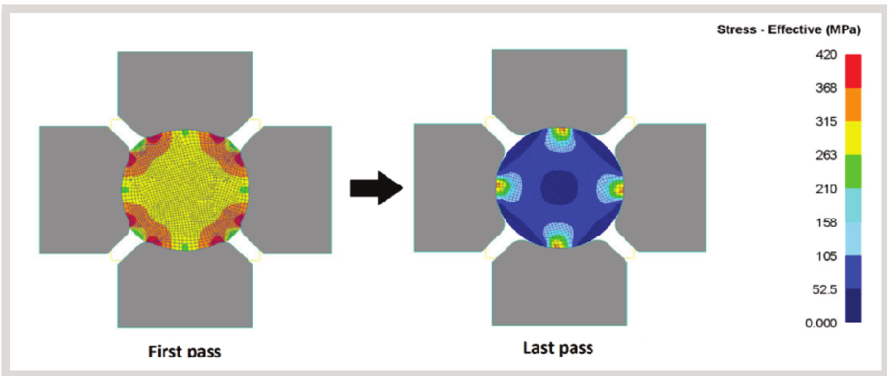
Stresses induced at four-die forging and two-die forging operations



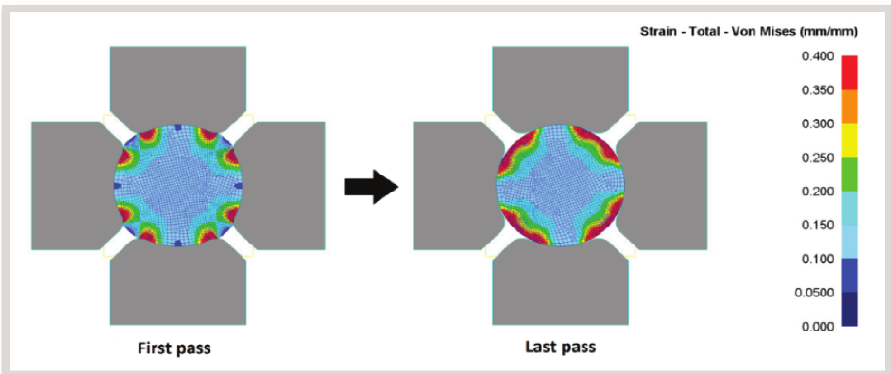
Strain at four-die forging and two-die forging operations

Four - die forging technology provides tolerances in the range from ± 0,8 to 2,0 mm depending upon the cross-sectional size of the product. In order to achieve tolerances as close as that, the forged parts after rough forging are either finished in specially shaped dies or finish-forged without reheating in a special finishing FDFD right after initial rough forging.

Finishing operation can be performed using either flat or channel dies. Finishing with four channel dies gives a 60 – 80 per cent higher output as compared to finishing using four flat dies.



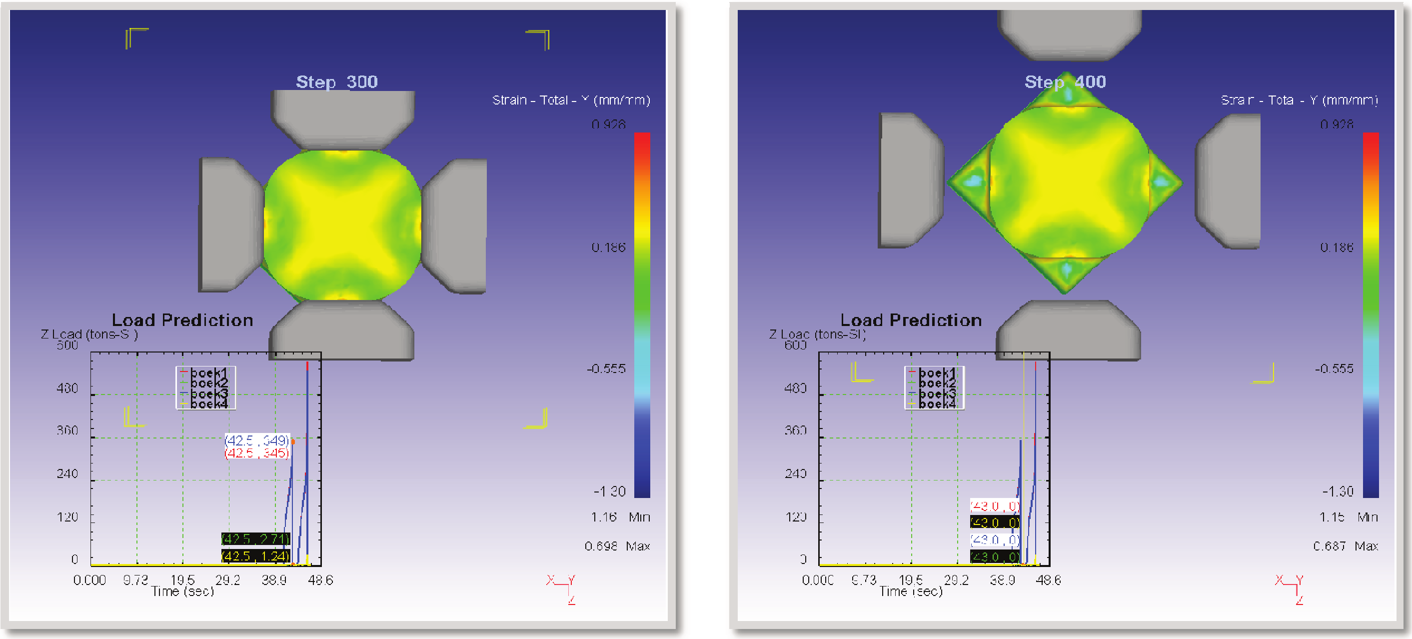
Stresses induced at finishing with four dies



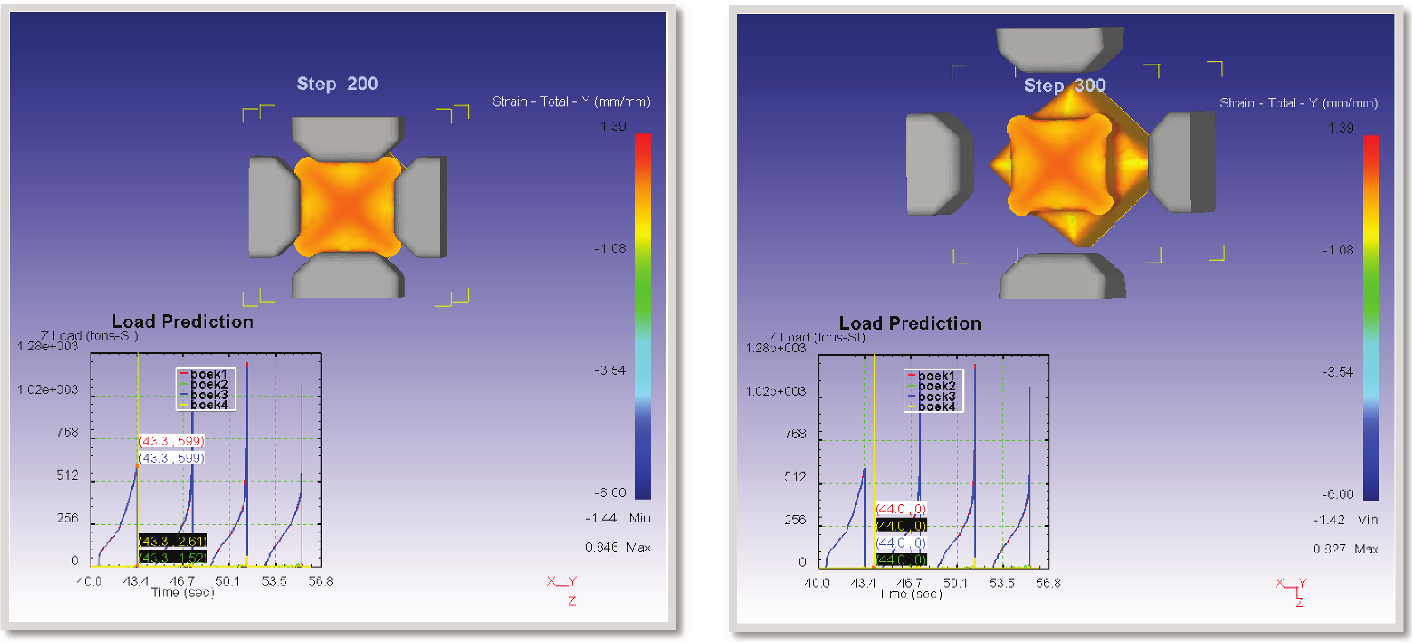
Strain at finishing with four dies

Finite element analysis of forging processes

The analysis of various technologies employed to forge ingots between two and four dies was conducted using the software package, ***DEFORM 3D***, which is intended to study three-dimensional (3D) metal behavior at various metal forming operations and further specially adapted for forging processes performed on RFM's and on a forging press equipped with FDFD.



Ingot forging in FDFD with no metal spreading between the dies (Strain)



Ingot forging in FDFD with metal spreading between the dies (Strain)

Comparative analysis of eight different forging techniques applied to initial ingots of equivalent size provided the following results:

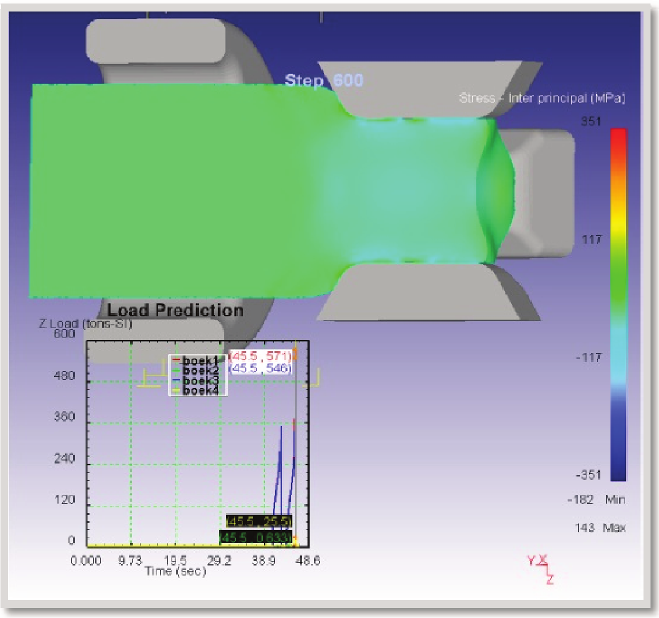
1. In contrast to two-die forging technique, mainly compressive stresses are generated at forging operation performed in FDFDs. Moreover, the stress distribution pattern when forged in FDFD is much more advantageous if compared not only with the two-die forging method, but also with the forging technique used on radial forging machines.

2. It has been ascertained that the maximum longitudinal and transverse compressive stresses when forged in FDFD with metal spreading between the dies are significantly (2–2,8 times) higher than the maximum compressive stresses generated not only at a two-die forging operation, but also at forging of equivalent initial ingots in FDFD without metal spreading between the dies.

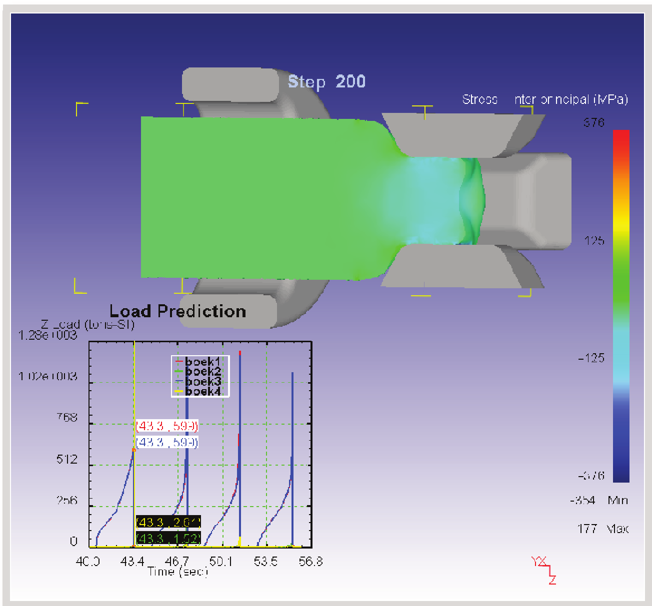
3. Calculations of metal damage indices made according to the Cockroft & Latham methods proved that metal fracture in a component produced by means of two-die forging metal is going to happen much earlier than in a component forged in FDFD.

4. It was demonstrated that the highest values of principal deformation were obtained when forged in FDFD with metal spreading between dies. It means that a forging process performed in FDFD generates more advantageous conditions for metal deformation treatment as compared to the two-die forging technique and forging technique employed on radial forging machines.

5. Forging operations according to FDFD technologies provide a significant deformation heating of metal which serves either to eliminate or at least to reduce the re-heating requirements.



Ingot forging in FDFD with no metal spreading between the dies (Stress)



Ingot forging in FDFD with metal spreading between the dies (Stress)

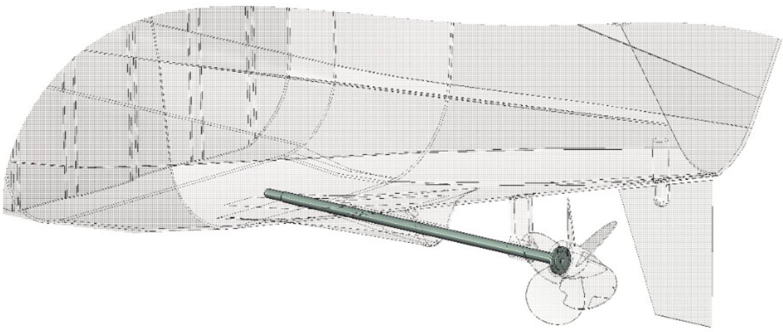
Products

Naval propeller and intermediate shafts. Wind turbine shafts

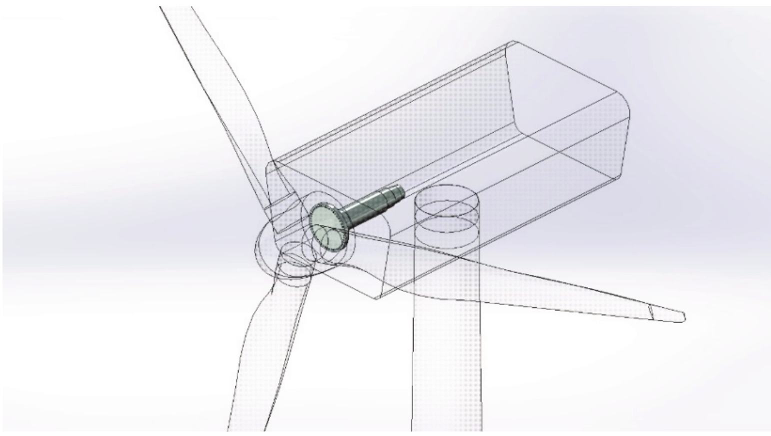
The technologies to produce the forgings for naval propeller and intermediate shafts as well as wind turbine shafts by using the forging on forging presses with FDFDs were developed.

These technologies ensure the fine-grained metal structure across the whole cross-section due to the intensive plastic deformation in FDFD and also the effective twisting of the structure (fibres) around the longitudinal axis of the forging.

The technology to produce the forgings for naval propeller and intermediate shafts was introduced for the 25MN forging press and proved not only high quality of the produced forgings but also provided the increase of the productivity in 2,0 – 2,3 times in comparison with the conventional two-die forging. Moreover, all forging process is accomplished during one ingot heat.



Ship propeller shaft



Wind turbine shaft


LOCK
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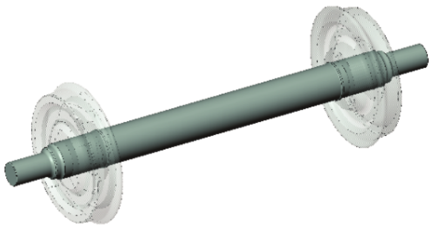
Axles of railway carriages and locomotives

The technology to obtain the near-net-shaped forgings for the axles of railway carriages and locomotives by using high-output forging on forging presses with FDFDs was developed and brought to the commercial level.

The technological process provides:

- the obtaining of the forgings with the variable cross-section and with the minimal machining allowances;
- homogenous fine-grained metal structure due to the intensive plastic deformation in FDFD;
- machining allowances – 10 – 12 mm ;
- tolerances for diameters - +2 / -1 mm;
- increase of the output by 70 – 100 % in comparison with the conventional forging on presses or forging hammers.



Wheelset of a railway car

Hollow products with square, rectangular and with other complex cross-sections

The technologies to produce the hollow products with square, rectangular and with other complex cross-sections by forging on forging presses with FDFDs were developed and brought to the commercial level.

A tubular blank or a tube with a certain diameter, which could be obtained by using any known technological process, are required to manufacture such products.

The forming of the required profile of the products is carried out on a forging press with FDFD by using the special tooling and according to the developed deformation schedule.

Hollow products of different cross sections

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

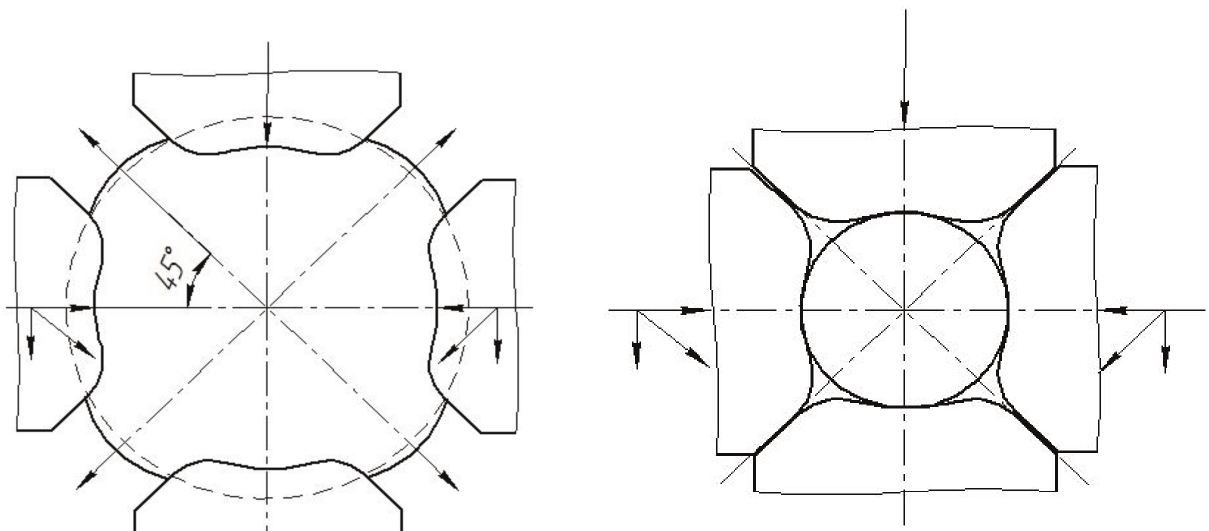
№	Step	Tool type	Manipulator movement	Start Ø, mm	Final Ø, mm	Manipulator movement	Manip-tor rotat. (step),deg	Manip-tor rotation (continuou)	Reheating	T,^{0}C	Time sec.
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1	Flat	Trasl.	**600**	530	200	0	0		1240	15
	2	Flat	Trasl.	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**
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**

Presented in Table 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 applied on 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 workpiece reheating is required. 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 to workpiece reheating and dies changing).

When forging in a FDFD (**technology No. 2**), 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 workpiece reheating as well as no dies changing are required to perform finish forging steps, since the same set of dies having concave surfaces is employed both for rough forging (1st to 9th passes) and for finish forging (10th and 11th passes).

Therefore, comparison of two forging methods for ingots and blankets proves the advantages of FDFD forging method over two-dies classic forging technique.



a) ***b)***

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

Metal saving

Four-die fording schedule implemented in a FDFD of a special design generates compressive stresses in circular peripheral area of a workpiece which results in defect-free forged parts. The benefits are as follows: a thinner poor surface layer to be removed at finish surface machining and thus a higher good metal yield.

Besides, since reheating requirements are significantly reduced, burned metal loss is significantly reduced, too, and it also contributes to a higher good metal yield and thus to considerable metal saving.

Energy consumption

Energy consumption for forging operation performed in a FDFD is much lower as compared to conventional two-die forging process on a press. The energy saving is achieved due to a higher efficiency of the forging process which results from practically eliminated lateral spreading of material. With no spreading effect, all the material deformed at each single reduction is forced to stretch along the workpiece longitudinal axis. Energy saving at initial parts heating to reach forging temperature is achieved due to reduced reheating requirements.

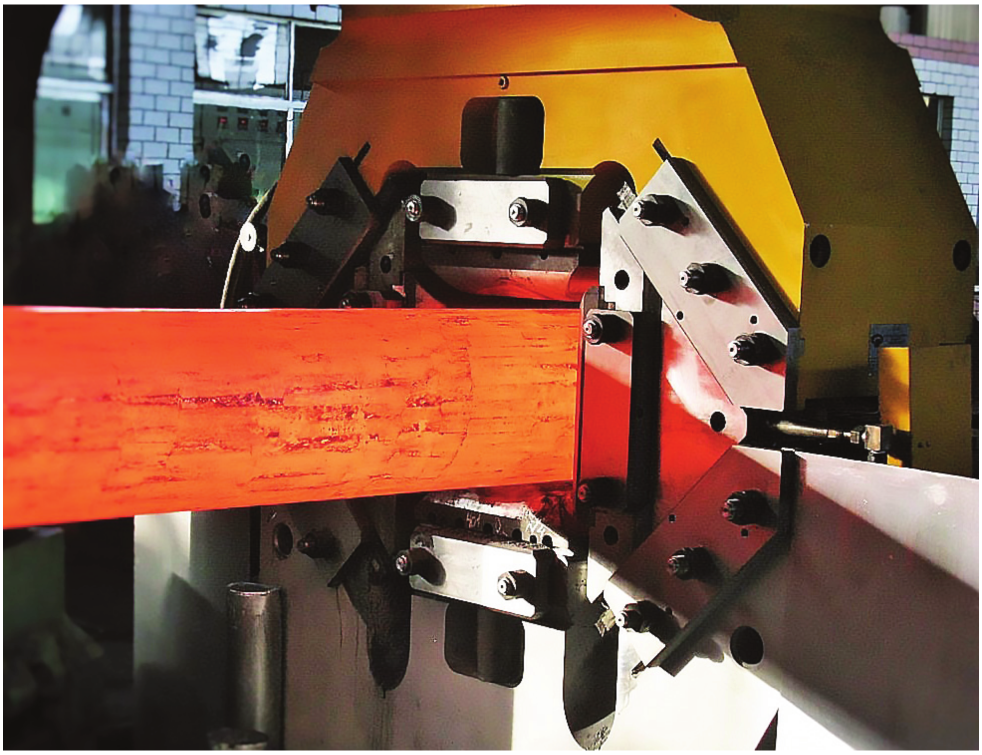
FDFD on a 40 MN press (Turkey)

Economical efficiency of the process

Calculation of the economic efficiency of the device application in production of forged parts in 4Х5МФС (X38CrMoV5-1) steel grade (DIN 1.2343 or AISI H11) on a 20 MN press was made on the basis of actual process parameters, which provided for the following benefits:

- 2 times higher forging output;
- 9 per cent increased good metal yield;
- 1,5 times closer allowances for finish surface machining and 1,5 times closer allowances for finish peeling on parts in diameters of 300-400 mm, which means 40 kg metal saving per 1 tonne of forged parts.

Economic efficiency has been calculated to be more than 300$ per 1 tonne of forged parts.



Production of forged parts with minimized allowances for finish surface machining on a 30 MN press (China)

For a more detailed calculation of economical efficiency of four-die forging devices the following issues shall be taken into consideration:

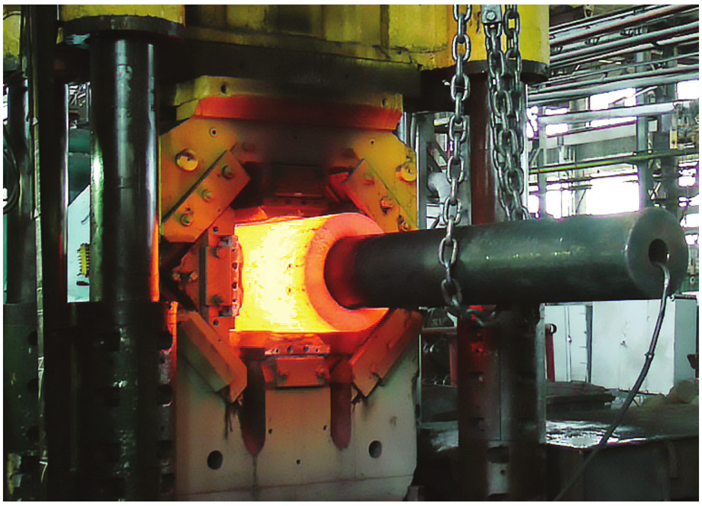
- Reduced energy consumption for metal heating (gas or electricity);
- Reduced energy consumption at forging operation (electricity);
- Reduced labour input at forged parts peeling operation due to a thinner metal layer to be peeled-off.

Considering the above-mentioned benefits we can say that actual savings at four-die device employment are even higher.

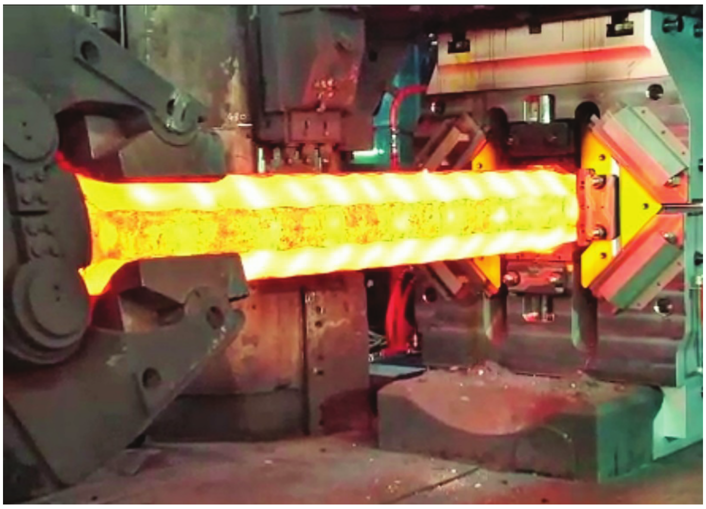
Long-term operation of four-die forging devices installed on various presses in industry proved high reliability of the device design

There are up to 30 four-die forging devices as of 2023 installed at manufacturing facilities. Three four-die forging devices are employed now at Corporation VSMPO-AVISMA (located in the city of Verkhnyaya Salda). Two of them are installed on 20 MN presses and one device is used on a 25 MN press.

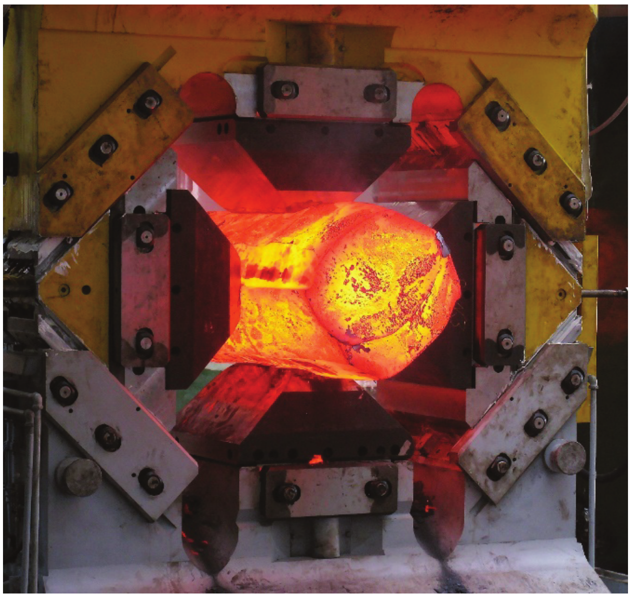
Four-die forging devices installed on presses in capacities from 5 MN to 120 MN are employed in production in Ukraine, Germany, Spain, China, Italy, Brazil, Russia, India, South Korea and Japan.



Pipe forging in FDFD on a 25MN press



High-alloy stainless steel ingot forged on a 30 MN press (Italy)



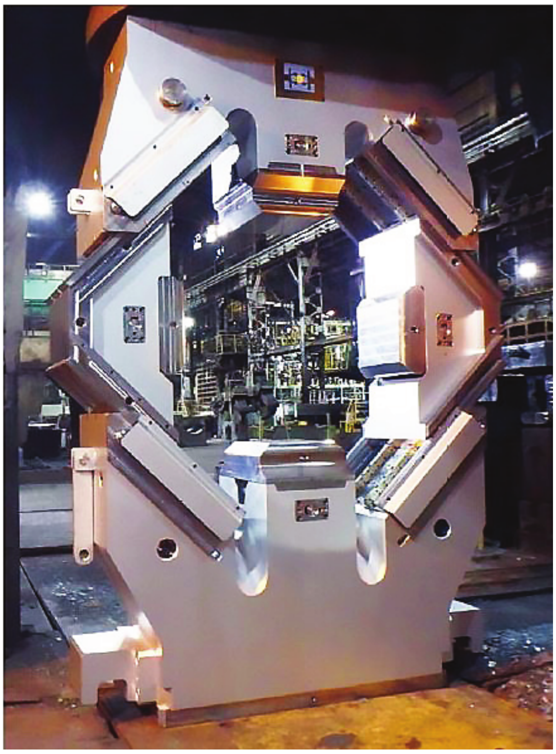
FDFD on a 30 MN press (China)

FDFD employed on a 25MN press to forge titanium billets at VSMPO-AVISMA plant

Manufacturing of FDFDs

The production of a four-die forging device is possible at the enterprises - partners of our company. Such companies are Officine Meccaniche Zanetti (OMZ) Italy and Japan Steel Works (JSW) Japan, which have experience in manufacturing FDFDs for hydraulic forging presses of various designs.

FDFD made in OMZ for 30 MN and 40 MN presses



FDFD made in JSW for 30 MN press

The manufacturing company provides the customer with all relevant certificates (chemical analysis of materials, mechanical properties, non-destructive testing, dimensional control), performs control of an assembly process, inspection, packaging and delivery to any place in the world, as well as assembly and testing of the device at the customer's enterprise.

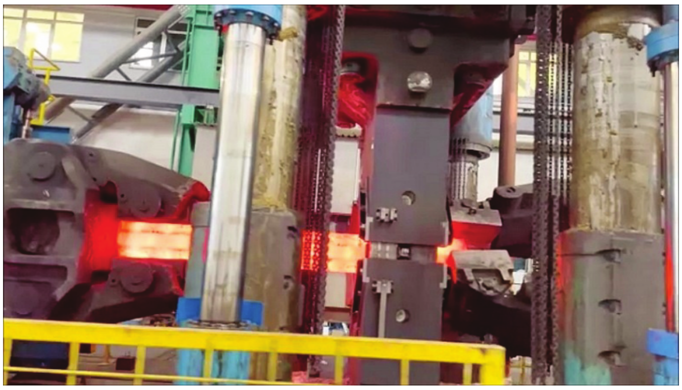
Individual approach

FDFD on a 45MN press (China)

Four-die forging devices are designed and manufactured to suit individual features of a customer's press depending on its design, specifications, operating conditions as well as sizes and material grades of initial ingots (billets) and finish products.

Maximum benefits of four-die forging devices can be achieved when the devices are built in production line of automatic forging plants. Automatic forging plants equipped with four-die forging devices allow to perform the forging process under isothermal conditions which results in considerably higher metal quality.

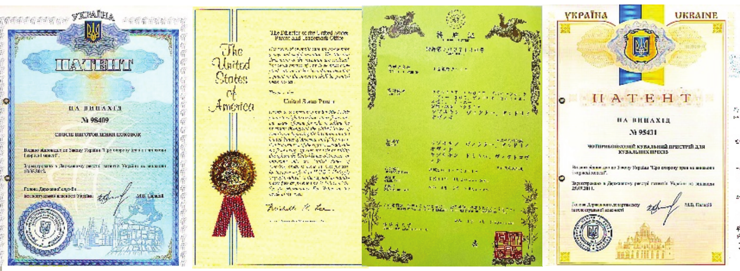
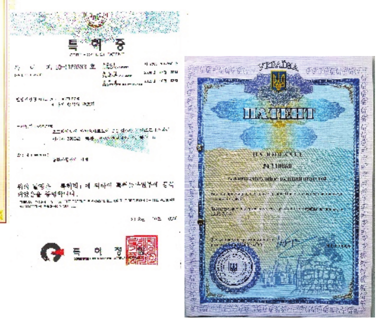
The highest efficiency of FDFD operation is achieved on presses with two manipulators.



Forging in FDFD on a 40 MN press with two manipulators (Turkey)

Under a license agreement, Lazorkin-Engineering develops FDFD for any forging press, supplies a complete set of design documentation for this device and assists in the manufacture and commissioning of the device at the customer's enterprise.

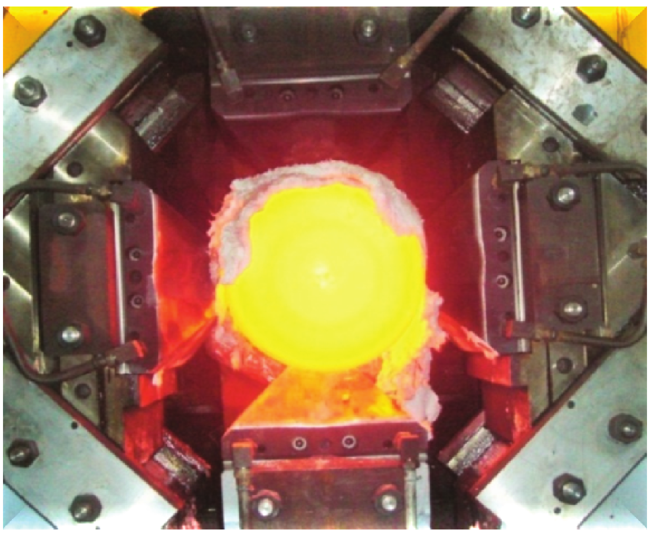
In addition, we develop optimal forging technologies for the entire range of customer ingots and provide assistance in mastering these technologies.

Patent protection

The design of the four-die forging device, as well as the four-die forging technology, are protected by more than 70 patents, namely:

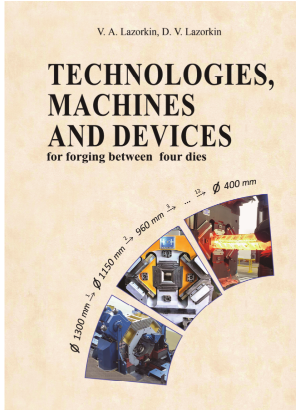
1. European Patent No. 2540411 B1.
2. US Patent No. 9283614 B2.
3. Japan Patent No. 7037140.
4. Patent of the Republic of Korea No. 10 - 2209657.
5. Patent of the Republic of Korea No. 10 - 2308882.
6. Patent of the Republic of Korea No. 10 - 1189333.
7. Chinese Patent No. 799397. Four-die forging device.
8. Brazilian Patent Application No. BR 11 2013 014955 A2.
9. Germany Patent No. 602011029473.3.
10. Patent of Ukraine No. 95431. Four-die forging device for forging presses.
11. Patent of Ukraine No. 98409. Method for manufacturing forgings.
12. Patent of Ukraine No. 101909. Method for replacing dies in a forging device.
13. Patent of Ukraine No. 118068. Four-die forging device.
14. Patent of Ukraine No. 125676 Four-die forging device for forging presses.
15. Patent of Ukraine No. 125131 Four-die forging device for forging presses.
16. Patent of Ukraine No. 102329 Four-die forging device.



Forging a heat-resistant alloy in FDFD on a 25 MN press

Forging a square section forging in FDFD on a 30 MN press (Japan)

More information about the four-die forging devices is available in the following publications:



1. Technologies, machines and devices for forging between four dies: monograph / V. A. Lazorkin, D. V. Lazorkin. – Zaporozhye : STATUS, 2019. – 348 p.
2. V. A. Lazorkin, N. P. Petrov / Proc. 16th IFM 2006, Oct. 15-19, Cutlers Hall, Sheffield, UK, p. 269 – 276.
3. V. Lazorkin, Y. Melnikov./ Proc. 18th IFM 2011, Sept. 12 - 15, Pittsburgh, PA, USA. p. 326 – 332.
4. V. Lazorkin, D. Lazorkin ./ Proc. 19th IFM 2014, Sept. 29 – Oct. 3, TokyoBay Area, Japan. p. 210 – 214.
5. J. R. Gonzalez, P. F. David, J. Cordon, J. M. Llanos. FEM simulation of the new radial forging device process at Sidenor. Proc. 17th IFM 2008, Nov. 3-7 Santander, Spain, p. 237-243.
6. V.A. Lazorkin, D.V. Lazorkin. Four-die forging devices in primary metal production. Kovarenstvi. Rijen 2015/55, c. 26-30.
7. V. Lazorkin, D. Lazorkin , S. Kuralekh. New design solutions of forging devices (FDFD) and open-die forging technologies. Proc. 20th IFM 2017, Sept. 15-19, Congress Graz, Austria, p. 476-485.
8. Roberto Tiburcio C. Frota Junior, Gustavo Acarine De Campos, Paulo :Augusto Morais De Oliveira, Gerson Graciano. Comparison between four die forging device and conventional forging processes of cold work tool steel. Proc. 20th IFM 2017, Sept. 15-19, Congress Graz, Austria, p. 545-553.
9. Masaki Todokoro, Akihiro Aoyama, Shinji Tanaka, Yasuyuki Kumagai, Viktor Lazorkin, Dmitriy Lazorkin. Improving the Efficiecy of the Round Bar Forging Process by Four Die Forging Device (FDFD). Japan Steel Works (JSW) technical report No. 72 (2021.11).
10. V. Lazorkin, D. Lazorkin, R. Onischenko, S. Kuralekh. New Design Solutions of Four-Die Forging Devices (FDFDs) and Their Technological Capabilities. FIA Magazine I November 2020, p. 110-116.

Forging a stainless steel ingot in FDFD on a 30MN press (Brazil)

LAZORKIN

Lazorkin – Engineering, LLC

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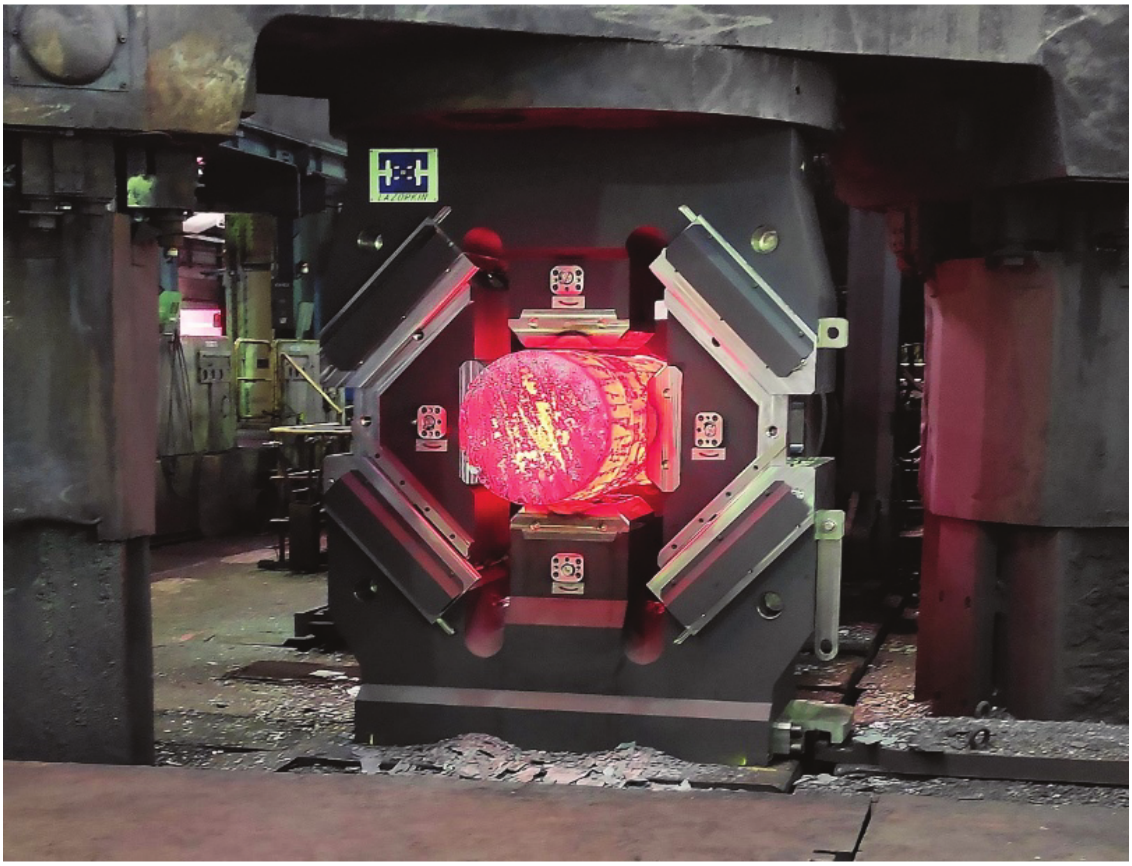

FDFD on a 30MN press (Japan)

List of Manufacturing Plants Where FDFDs are Installed.

Rated Press Force (RFM) MN	Year of Manufacturing	Company (Country)	Qty of FDFDs (Units)	Lubrication System	Cooling System	Self-Lubricated Sliding Bearings
1	2	3	4	5	6	7
5	1990	UKRNIISPETSSTAL (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 TYAZHPRESSMASH (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 BUMMASH (Russia)	**1**	Yes	Yes	No
20	2008	OOO 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., Ltd (China)	**1**	Yes	Yes	No
20,30	2010	BAOTOU IRON & STEEL (Group) Co., Ltd (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. EDELSTAHLWERK (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
35	2017	RUSPOLYMET (Russia)	**1**	No	Yes	Yes
15	2018	MIDHANI (India)	**1**	Yes	Yes	No
22	2019	SeAH (Korea)	**1**	No	No	Yes
30	2019	JSW (Japan)	**1**	No	No	Yes
29,4	2022	(Japan)	**1**	No	No	Yes
40	2022	ASIL CELIK (Turkey)	**1**	No	No	Yes