FOUR-DIE FORGING DEVICES (FDFDs) AND FORGING TECHNOLOGIES DEVELOPED BY LAZORKIN-ENGINEERING COMPANY

Dr. Viktor Lazorkin, Technical Director, Lazorkin-Engineering LLC, Zaporozhye, Ukraine.
Dmitriy Lazorkin, General Director, Lazorkin-Engineering LLC, Zaporozhye, Ukraine.
Roman Onischenko, Chief Designer, Lazorkin-Engineering LLC, Zaporozhye, Ukraine.
Sergey Kuralekh, Representative in EU countries, Lazorkin-Engineering LLC, Berlin, Germany.
E-mail: lazorkin.engineering@gmail.com, sergey.kuralekh@yahoo.com

Many years of experience in designing of the Four-Die Forging Devices and the operational experience for these devices together with the different hydraulic forging presses have proven that in every particular case an individual approach is required to select the proper FDFD design and the optimal forging technologies for it. The main selection criteria for the device design and the forging technology are as follows: high metal quality and high producibility of the process, reduction of the forging production cycle and high precision of the produced forgings.

The main types of design solutions for FDFDs developed by Lazorkin-Engineering company are presented in this paper. Also, this paper contains the description of capabilities for each presented type of FDFD design and specific examples of forging technologies as well as examples of the products, which can be manufactured using these devices. Furthermore, the paper provides the information about the industrial application of FDFDs worldwide.

KEYWORDS: FDFD – FORGING – OPEN-DIE – PRODUCIBILITY – QUALITY – PRECISION – EFFICIENCY

1. DESIGN SOLUTIONS FOR FDFDs

Lazorkin-Engineering company has developed various design solutions for FDFDs depending on the Customer's problems to be solved. These design types can be split into two big groups with regards to the movement model of the dies (1).

The **first group** includes the devices, which have the bottom die always fixed; under the action from the movable cross-beam of the press onto the top body of the device the latter moves together with the top die fixed on it simultaneously with the lateral dies, which move not only towards each other but also move in the same time towards the bottom die thus creating additional shear deformations in the treated workpiece (Fig.1).

Fig.1 – Typical view of FDFD belonging to Group 1

The **second group** includes the devices, which have all four dies moving uniformly towards the central axis of the device (when dies approach to each other) and uniformly get away from it (when dies move away from each other) (Fig.2). This principle is also used for Radial Forging Machines (RFMs).

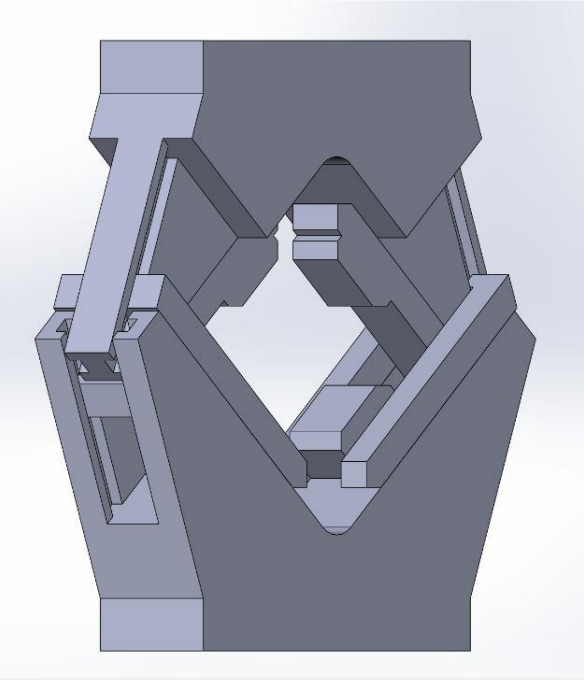

Fig.2 – Typical view of FDFD belonging to Group 2

This being said, all FDFDs cane be divided by design and technological features into several groups.

By technological features:

- for rough forging of ingots;
- for calibration of forgings;
- for rough forging of ingots and subsequent calibration of forgings using one FDFD;
- for producing mainly the forgings with the round cross-section including those with variable cross-section;
- for producing the forgings with the round and square cross-sections;
- for producing mainly the forgings with the square and rectangular cross-sections;
- for producing the hollow forgings;
- for producing the forgings having the cross-section with the complex special profile.

By design features:

- with cooling system for the dies or without such system;
- with force feed lubrication system for the sliding bearings;
- with self-lubricated sliding bearings;
- with the mechanism for quick replacement of all four dies simultaneously;
- with quick fix system of FDFD to the top cross-beam of the press or to its top die;
- with additional guide posts;
- with springs to open FDFD and without fixing the device to the top cross-beam of the press or to its top die;
- with mechanisms controlling the distance between the opposite dies.

Let us take a closer look at several developed by our company FDFD design solutions, which belong to the first and second groups.

1.1. The most common is the FDFD design solution, which is used for the rough forging of ingots and subsequent calibration of forgings with the round and square cross-sections in one and the same FDFD. Such design scheme has self-lubricated sliding bearings and the mechanism for quick replacement of all four dies simultaneously (Fig.1). Four-Die Forging Device may have either one or several die sets depending on the range of used ingots and the nomenclature of the produced forgings with the round and square cross-sections.

The special dies are used to produce the forgings with the square and rectangular cross-sections (Fig.3).

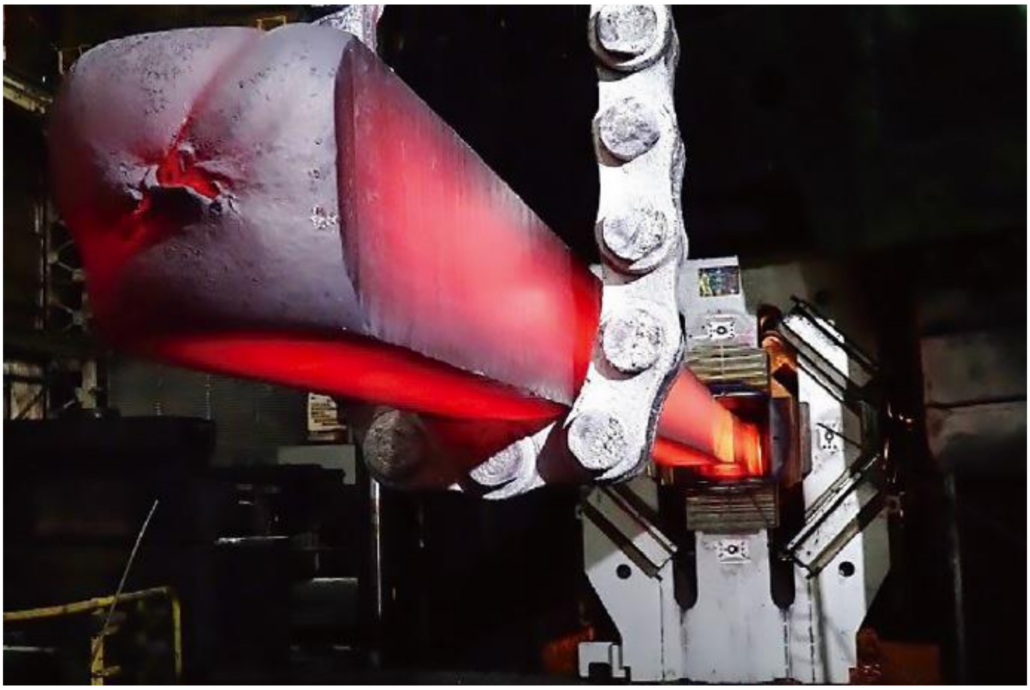

Fig.3 – FDFD equipped with the special dies to produce the forgings with the square cross-section

1.2. A special FDFD design solution was developed to produce the forgings with the rectangular cross-section. This solution contains the sliders with the new design, which ensure the control of the distance between the lateral dies, as well as the dies with the special design (Fig.4). The design of the dies is the same as that for the dies used to produce the forgings with the square cross-section.

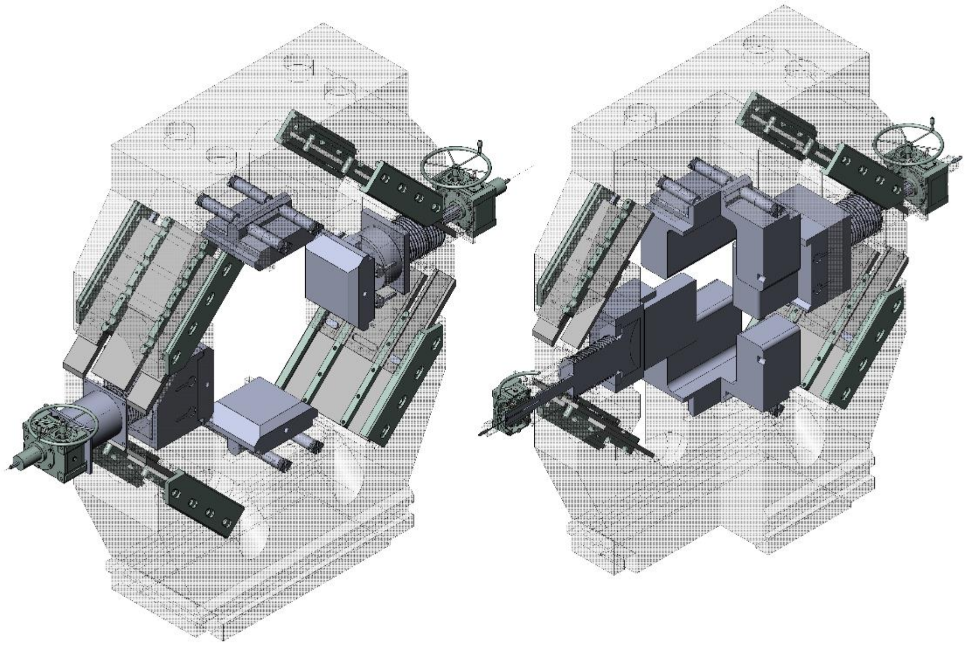

Fig.4 – Design of FDFD to produce the forgings with the rectangular cross-section

Two options can be used to produce the forgings with the rectangular cross-section:

1st option: Original sliders need to be removed from FDFD, which is used for production of the forgings with the round and square cross-sections. Then the sliders with mechanisms controlling the distances between the opposite dies should be installed instead of original ones. Further, the original top and the bottom dies should be replaced by the dies with the special design to produce the forgings with the rectangular and square cross-sections.

2nd option: Use the FDFD of the special design, which already has the sliders with mechanisms controlling the distances between the opposite dies and the dies with the special design to produce the forgings with the rectangular and square cross-sections installed.

1.3. FDFD design solution with additional guide posts (Fig.5) is suggested for those rare cases, when during operation of the forging press the significant lateral displacements of its movable cross-beam relative to its static structure occur and it is very hard or impossible to rectify.

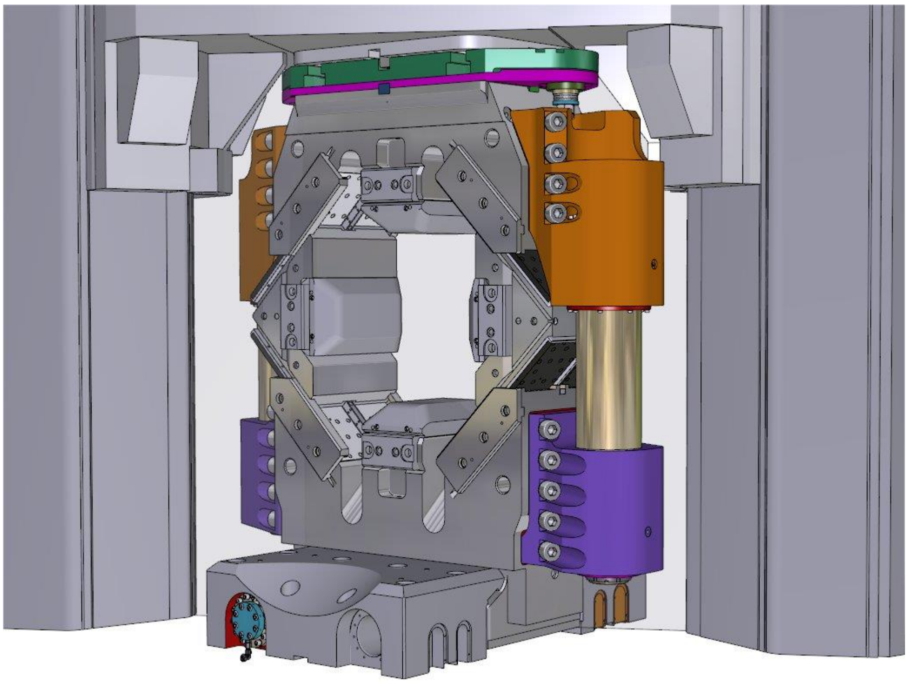

Fig.5 – Design of FDFD with additional guide posts

The strength of the additional guide posts is calculated in such manner that they can ensure the reliable operation of FDFD without the displacement of the device top body in relation to its bottom body.

1.4. The cooling system for the dies is very rarely applied and is needed only for those cases when FDFD is used for the continuous forging of the big batches of the workpieces made of carbon or low-alloy steels, e.g. for forging of carriage or locomotive axles. So, this is for those rare cases, when even the most modern materials cannot withstand the heating temperatures and the stresses emerging in FDFD parts during the intensive continuous forging.

1.5. The FDFD was designed and manufactured to forge the workpieces with the small cross-sections (Ø 300-400 mm). Such FDFD contains the guide posts and the springs, which allow to open the forging device when the press cross-beam goes upwards (Fig.6).

Fig.6 – Design of FDFD with guide posts and metallic springs

This solution allowed to remove the mechanism to fix the top body of the forging device to the movable cross-beam of the press and in this way to decrease the time required to remove FDFD from the working space of the press when tools need to be changed. The disadvantage of this FDFD design solution is that it cannot be used to forge the ingots with the big cross-section as it is impossible to manufacture the metallic springs to lift the movable parts of the forging device, which have a high weight, to the big height.

1.6. To enable the forging of the ingots with any cross-section, including the ones with the big cross-section, our company developed the design of FDFD with gas-hydraulic springs, which are installed between the top and the bottom bodies of the forging device and allow to lift the top body relative to the bottom body (Ukrainian patent No. 118418) (Fig.7).

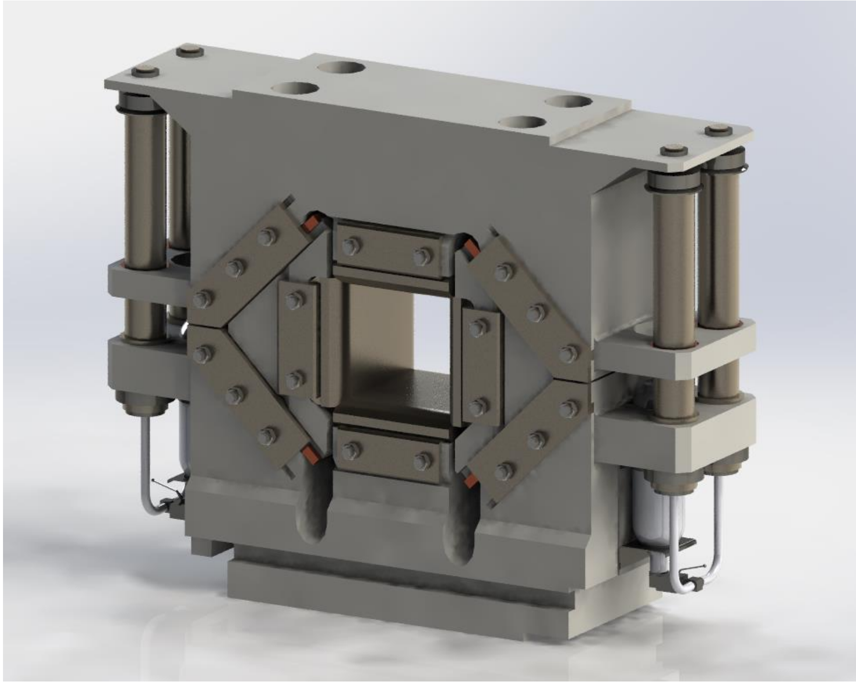

Fig.7 – Design of FDFD with guide posts and gas-hydraulic springs

Using such type of springs, a Four-Die Forging Device can be manufactured to forge the ingots with any size and weight. In this case the mechanism to fix the top body of the forging device to the movable cross-beam of the press will not be required.

1.7. All FDFDs are designed as wedge systems, which transfer the load from the movable cross-beam of the press via the top body of the device to the sliders along their inclined surfaces and to the dies. The sliding bearings are installed on these inclined surfaces, which take up the forces from the press during forging.

Earlier we used systems with the force feed of liquid lubricants onto the sliding bearings using a pump. A "steel-bronze" pair was used for these sliding bearings. In recent years we changed to the application of the self-lubricating sliding bearings, which use solid lubricants pressed directly into the sliding bearing.

The following pairs are used currently as self-lubricating sliding bearings in our FDFD design solutions: "steel – WearComp®" and "steel – metallic composite material with uniformly distributed solid lubricant". The self- lubricating sliding bearings are currently used in all our devices and give a good account of themselves.

1.8. In some (rare) cases the self-lubricating sliding bearings can quickly go out of service due to the bad technical condition of a forging press. Then we use the system with the force feed of liquid lubricant (dripping method) onto the sliding bearings using a pump built into FDFD.

For this purpose, we have developed a conceptually new drop-feed lubrication system onto the "steel – bronze" sliding bearings. All the lubrication system, including pumps, tanks with lubricant and control elements are located in one of FDFD bodies. The operation of the pumps is effected on account of the FDFD top body moving in relation to its sliders. Upon the command from the control panel of the forging press the drop-feed lubrication system can be switched on and off in any moment using the wireless communication (Ukrainian patent No. 125676) (Fig.8).

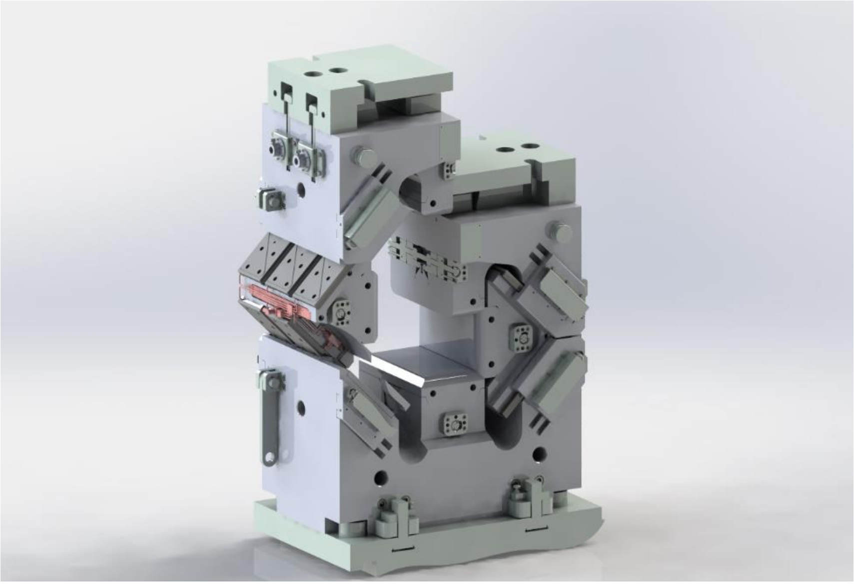

Fig.8 – Design of FDFD with new drop-feed lubrication system

1.9. As per the request from the Customer producing the rolled metal products our company developed the equipment system and the technology to apply FDFDs for the pilger rolling of tubes (Fig.9).

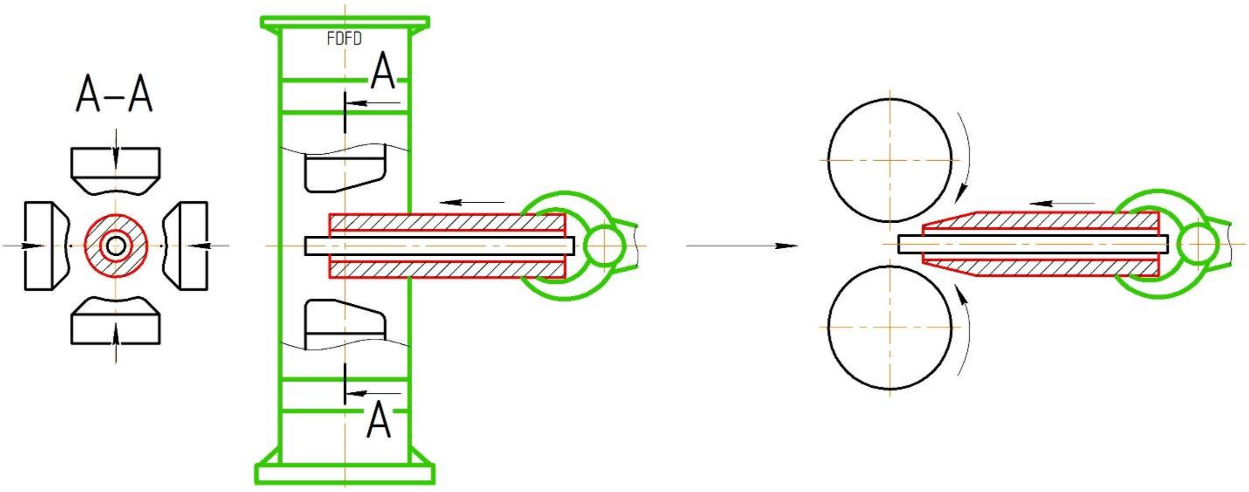

Fig.9 – Design scheme of FDFD used for the pilger rolling of tubes

The process of the pilger rolling of tubes is characterized by technologically inevitable metal losses at starting section and at pilger head. Moreover, the total metal losses due to technological scrap can be up to 6-9% from the weight of initial workpiece. There is also an increase of rolling time during unsteady rolling modes in addition to the metal losses due to technological scrap. This increase in rolling time can be up to 9-15% from the total productive time for pilgering process. The essence of our method lies in swaging of the front (or front and rear) end of a tubular bloom by the profiled dies of FDFD. A tubular bloom sits on a mandrel, which is inserted into it using the special press. This will allow to reduce the technological scrap by 40-50% and increase the producibility of a rolling mill.

We consider that the most promising is the scheme with the four-die uniform swaging of the tubular bloom ends in FDFD used with special radial forging machine with hydraulic or mechanical drive (Fig.10).

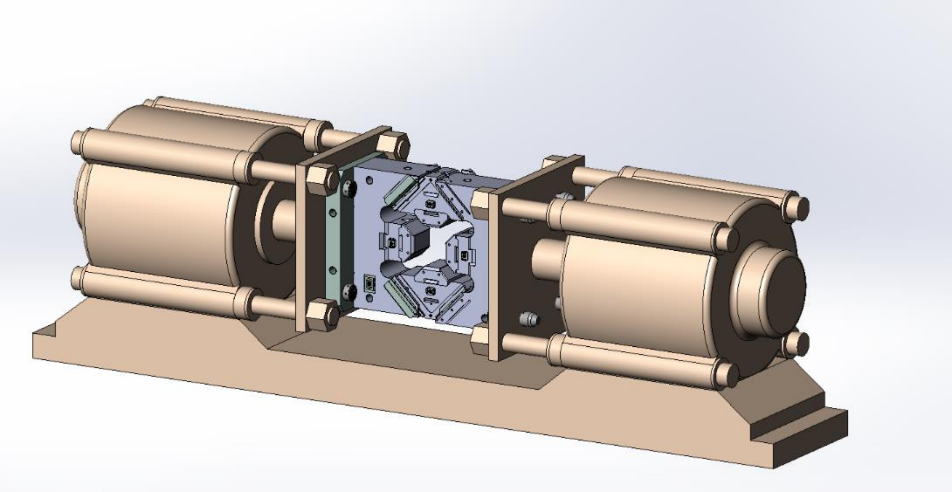

Fig.10 – FDFD used with special radial forging machine with hydraulic or mechanical drive

Our design scheme for FDFD from the second group, which has all four dies moving uniformly towards the central axis of the device (when dies approach to each other) and uniformly get away from it (when dies move away from each other), answers this purpose.

1.10. At the present time heavy wall pipes of a big diameter are produced above all by means of rolling, press forming, two-die forging in forging presses and radial forging machines. According to our sources it is possible to produce heavy wall pipes with diameter of up to 1120 mm and wall thickness of up to 200 mm using the made in Japan pipe-rolling plants with a push bench. Press formed steel pipes with outer diameter of up to 850 mm are produced usually using the horizontal hydraulic presses. It is possible to produce the tubes with diameter of up to 700-800 mm using the most powerful radial forging machines.

Two-die forging in forging presses is mostly used to produce the tubes with diameter of up to 1200 mm and with length of up to 10 meters. However, this technology has major drawbacks: big labor intensity, low producibility of the process, high variations in wall thicknesses of the pipe, low metal utilization factor.

Over the last years an increase in industrial demand in production of the large-sized hollow thick-walled forgings (outer diameter of 450 – 1500mm, wall thickness of 60- 250mm, length of 5000 – 12000mm) is observed.

Our company developed a technology to produce hollow thick-walled forgings using FDFDs installed to forging presses and special mandrels fitted into the cavity of a workpiece (Fig.11).

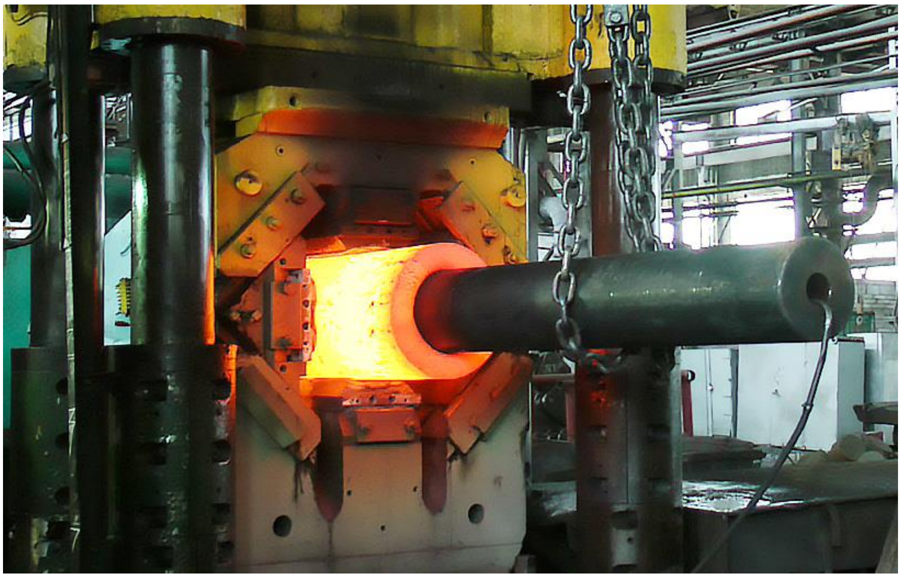

Fig.11 – Forging of a hollow workpiece on a mandrel in FDFD

The dies of FDFD are specially profiled. Hollow or solid ingots can be used as primary blanks as well as centrifugally cast hollow blanks.

Due to the fact that FDFD can be manufactured for any forging press (with forging forces up to 60, 120 MN and more) an opportunity has emerged to produce the heavy wall forged pipes with significantly bigger diameters and weights in comparison with the tubes produced in accordance with the known technologies.

2. ON THE FORGING TECHNOLOGIES FOR FDFD

The development of a technology for forging using FDFD starts from the thorough study of the existing Customer’s manufacturing process for forgings or, if a new production site is in development, the process starts from creation of the technological requirements for a new production. The development of new forging technology starts from selection of optimal manufacturing scheme for the production of forgings, which includes the selection of ingots, heating of ingots, rough and calibration forging of ingots and blanks on forging press, additional re-heatings of blanks and exchange of dies (as required), cutting or sawing of forgings, their restriking (as required) and heat treatment of forgings. The pivot in this technological process is the four-die forging technology using FDFD. As a result of this preparation work Customer sometimes brings significant changes into the whole technological scheme for the production of forgings, in particular: starts using ingots with other sizes and forms to start forging, changes the technological processes for re-heating and forging of ingots, starts using other equipment for cutting of the forgings, and sometimes performs a significant modernization of the forging press. A modernization of a forging press is usually done to enable a quick installation of FDFD in the working space of the forging press together with a reliable fixation of FDFD to it, as well as quick exchange of FDFD by other forging tools.

Our multiple Finite Element Method (FEM) based calculations of forging processes using FDFD as well as industrial experiments have shown that FDFD forging allows to achieve a severalfold increase for deformation rate at every single reduction in comparison with conventional two-die forging. This leads to significant increase of forging process speed and the workpiece at the same time does not fail. After such type of forging the quality of metal is always better if compared to the same parameter for other treatment types.

Thereat we almost always recommend to start the rough forging of ingots using FDFDs with big reductions, when the metal is forced to flow out between the dies. With this technology not only high producibility of the process is achieved as well as high metal quality due to the intensive deformation of workpiece, but also a possibility emerges to produce forgings in a wide dimensional range using one set of dies. In most of the cases FDFD forging is performed with one heating or an amount of re-heatings is reduced significantly.

Moreover, owing to application of developed by us deformation modes there are no tears on surfaces of forgings during the forging of not only medium alloy steels but also for high alloy steels and alloys. The maximum effect on process producibility and on quality of deformational treatment of metal is achieved at forging of ingots with square cross-section (2). When reductions of ingot with square cross-section occur at its ribs, a more intensive displacement of metal happens from the surface zones of an ingot to its axial zones as well as metal flow in direction of longitudinal axis in comparison with the reductions of an ingot with a round cross-section. This process ensures an intensive collapse of pores and cracks in cast metal, crushing of large-sized dendrites and carbides, eliminates a liquation of non-metallic inclusions, contributes to obtainment of fine-grained structure of metal in a forging.

Table 1 contains the examples of forging production using the conventional (two-die forging) and FDFD technologies.

Tab. 1 – Comparison of technologies for two-die and FDFD forging

COMPARISON OF TWO-DIE AND FOUR-DIE FORGING TECHNOLOGICAL SCHEMES

No.	Step	Tool type	Manipulator movement	Start Ø, mm	Final Ø, mm	Manip-tor movement	Manip-tor rotat. (step),deg	Manip-tor rotation (continuou)	Re-heating	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**

As per conventional technological process the forging at forging press is performed using two flat dies, then the flat dies are removed from the working space of the press and two profiled dies are installed to carry out a calibration of the forging (Technology No.1). During the forging process using two flat dies the workpiece rapidly cools down to temperatures lower than the permissible range of forging temperatures, so after the

9th pass the workpiece is sent for re-heating (refer to Table 1). The forging of an ingot with weight of 4300 kg is carried out at 23 passes and the time for forging in accordance with conventional technology (without reference to time required for re-heating and exchange of dies) makes up to 1195 seconds.

When forging using FDFD (refer to Technology No.2 in Table 1), the number of passes is 11 and forging time is 587 seconds, which is two times less than two-die forging. Moreover, no re-heating and replacement of dies for calibration are required, because one and the same set of dies is used for rough (passes 1-9) and calibration forging (passes 10, 11).

3. INDUSTRIAL APPLICATION

3.1. We have developed and matured in production a big number of different technologies for FDFD forging for the ingots varying in forms and sizes, made of different steel grades and alloys adapting to every specific condition at metallurgical production.

In most of the cases known to us from our practical experience in maturing FDFD forging technologies, a Customer procures a Four-Die Forging Device to increase the producibility of production process for the forgings with round or square cross-section and to increase the dimensional accuracy of these products (Fig.12).

Fig.12 – Calibration forging using FDFD

The author of this paper participated during three years in maturing of FDFD forging processes with 20 MN and 25 MN forging presses, directly working for the company at which site these FDFDs were installed. During this time a big volume of statistical data was collected for FDFD installed to 25 MN forging press, which covered the producibility improvements for forging the ingots with weights of 5, 7 and 10 tons, round cross-section, made from steel grades 40X, 40XH, 40XMA и 17Г1С produced by open arc smelting (EN analogues of these steel grades are as follows: 40X is equivalent to 1.7045; 40XH → 1.5711; 40XMA → 1.7223; 17Г1С → 1.0507).

It was established that the productivity of FDFD forging (Q) depends on the forging scheme, weight of an ingot and elongation ratio (forging reduction) (μ). Fig.13 contains the data with regards to the productivity of forging the ingots with weights of 5t (graphs No. 1 and 4), 7t (graphs No. 2 and 5) and 10t (graphs No. 3 and 6) using FDFD fitted to the 25 MN forging press.

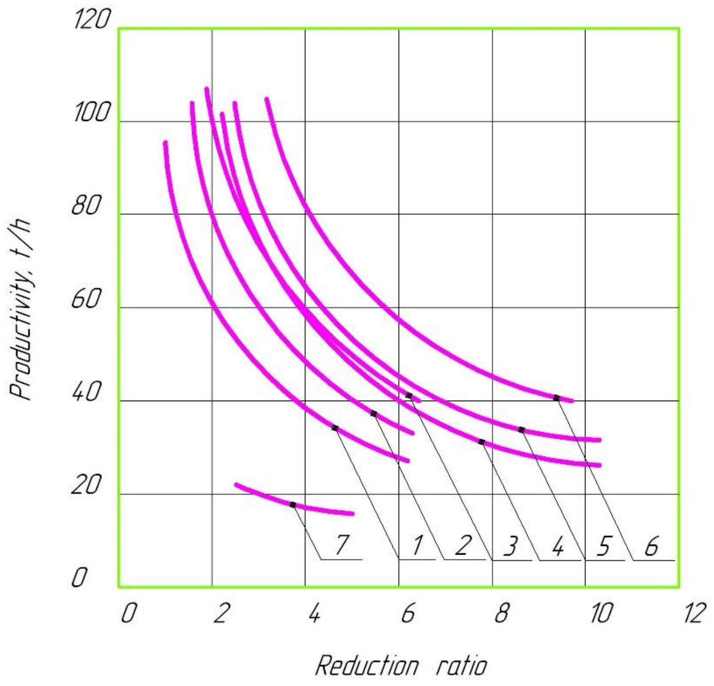

Fig.13 – Productivity vs reduction ratio when forging using FDFD

The graphs No.1-3 are related to FDFD forging technologies with no metal flow-out between the dies during the reductions and graphs No. 4-6 are related to the technologies with the metal flow-out between the dies. A conclusion can be made from these graphs that during the forging in FDFD with metal flow-out between the dies (graphs No. 4-6) the productivity of the process is significantly higher compared to the FDFD forging with no metal flow-out between the dies (graphs No. 1-3). Besides this, the productivity of FDFD forging improves also with the increase of ingot weight. A dependency of two-die forging process productivity for the ingot with weight of 5t on the elongation value is shown on graph No.7 for 25MN forging press (refer to Fig.13). It is evident from comparison of two forging processes for ingots that productivity for FDFD forging is 3 — 3,5 times higher in relation to the conventional two-die forging. In total more than 15000 ingots with weight of 5 — 10 t were forged to collect this statistical data.

During the process of mastering FDFD, the forging of ingot head, roughing-up of an ingot and its subsequent rough forging and calibration down to the final dimensions were carried out using one and the same set of dies and with one heating of an ingot. The tolerances for all dimensions of forgings with diameters from 280 to 600 mm were not more than ± 2mm. All forgings had geometrically precise round cross-section without any ellipticity. After forging a heat treatment was performed and, as required, the straightening using the straightening press, then shot cleaning in a blast cabinet. The surface quality of forgings after calibration in FDFD was approaching to the values of surface roughness for the workpieces produced by rolling. Under agreement with some customers the forgings were supplied without machining and ultrasonic inspection of forgings was performed on non-treated surfaces. In those cases, when customers required that forgings were to be supplied in turned condition, the allowances for the machining of forgings with diameters of 280 – 500mm were by 40-50% less compared to the allowances common for open-die forging (25 – 30mm). This helps to save from 30 up to 50 kg of metal per 1 ton of forgings. The quality of metal for all forgings produced by FDFD forging met all the requirements set by customers. Owing to the decrease of surface defects and decreased amount of workpiece re-heatings, the metal yield increased by 10 – 12%.

3.2. Throughout the work period of Lazorkin Engineering company we had customers for FDFD to produce the special products.

During the mastering of FDFD fitted to 20 MN forging press we tried out technology to produce the profiled forgings for railroad axles (axles for carriages and locomotives) (Fig.14).

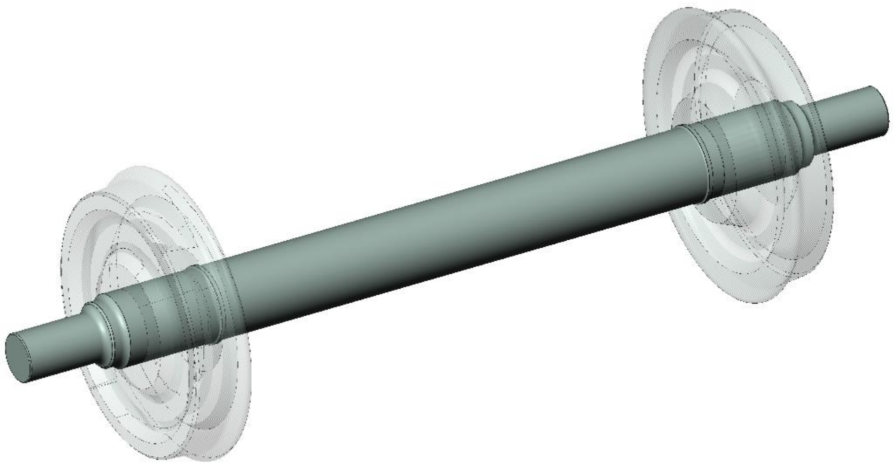

Fig.14 – Example of profiled forging for railroad axles produced using FDFD

The dies with special design were used in FDFD for this purpose. The produced forgings with variable cross-section had allowances of 10 – 12mm for diameters and tolerances were +2/-1 mm, which is comparable to the similar values for the forgings produced by radial forgings using 10 MN RFM SXP-55. The technological process to produce profiled forgings for railroad axles using FDFD is very promising as there is no need to use expensive RFMs and, as our researches have proven, the metal quality of the forgings is higher than the same parameter for the forgings produced using RFMs (1).

Our company developed the technologies to produce the forgings for marine propeller drive and intermediate shafts, wind turbine shafts and other special products using forging press and FDFD (Fig.15 and Fig.16).

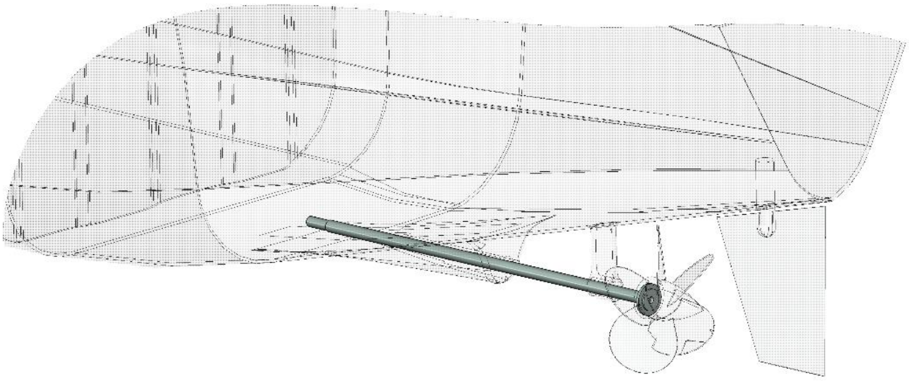

Fig.15 – Typical view of the marine propeller drive shaft

These technologies provide the fine-grained structure and high strength properties of the metal due to the intensive plastic deformation in FDFD along the whole cross-section and due to the effective twisting of the metal structure (fibers) along the longitudinal axis of the forging.

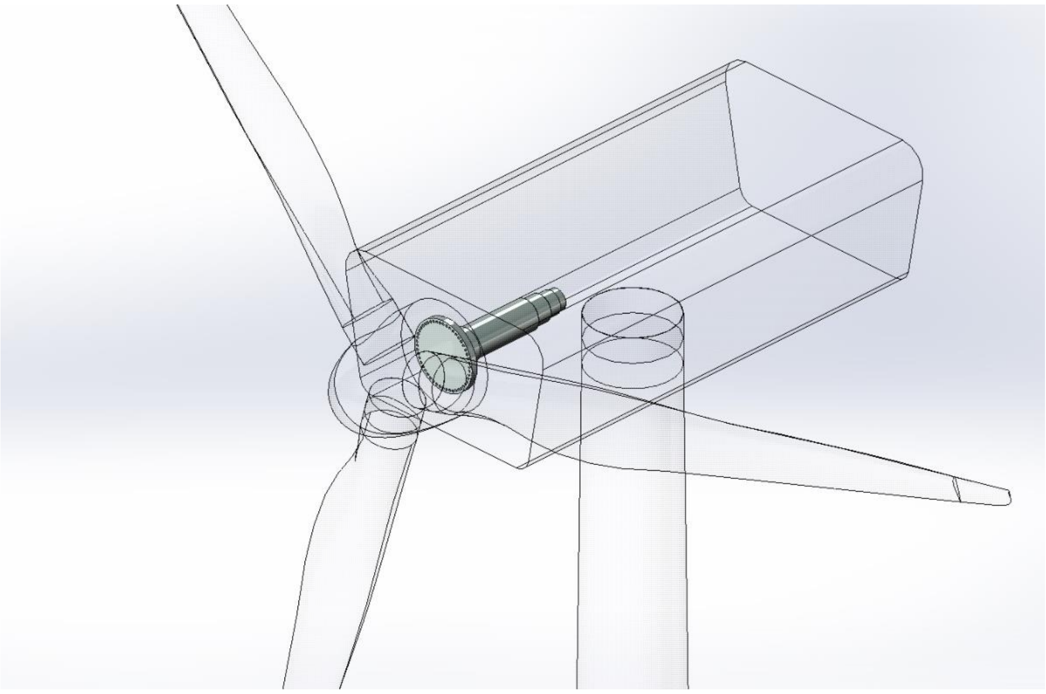

Fig.16 – Typical view of the wind turbine shaft

The technology to produce the forgings for marine propeller drive and intermediate shafts in FDFD was mastered for 25MN forging press and has proven not only the high quality of the produced forgings but also the increase in producibility in 2,0 – 2,3 times in comparison with the conventional two-die forging. Moreover, the whole forging process occurs with one heating of an ingot.

Our company developed and implemented the technologies to produce the hollow forgings with square, rectangular and other complex cross-sections using forging presses and FDFD (Fig.17).

Fig.17 – Typical profiles of special forgings produced using FDFD

To produce such special forgings the tubes with the certain diameters need to be used. These tubes can be produced in accordance with any known technological process.

The shaping of the required profile is carried out using the forging press with FDFD fitted to it, special tooling and in accordance with the developed deformation scheme.

At the present time 29 FDFDs are manufactured in accordance with our design for forging presses and radial forging machines for 26 metallurgical and machine-building companies in 10 countries worldwide. 3 four-die forging devices of 29 were manufactured for 1,25 and 1,6 MN RFMs of our design, the remaining 26 FDFDs were manufactured for forging presses with forces from 5 to 120 MN.

All design solutions for FDFDs and forging technologies for these devices are patented in 10 countries worldwide.

4. SUMMARY

1. Lazorkin-Engineering company developed various design solutions of four-die forging devices (FDFDs), which can be used with forging presses and RFMs of different types.
2. The most popular design solution of FDFD turned out to be the one, which has bottom die fixed and lateral dies move not only towards each other but they also go down towards the bottom die, thus creating additional shear deformations in a forged workpiece. Due to such die movements not only the high process productivity is achieved but also a high quality of forgings.
3. The application of FDFD fitted to forging presses and using the various types of dies allows to produce forgings with round, square, rectangular and variable cross-sections, as well as to produce hollow forgings with tolerances and allowances significantly smaller than those for two-die forging on forging presses according to the conventional technologies.
4. Technologies using FDFDs fitted to forging presses to produce the forgings for special products (railroad axles, shafts, hollow products etc.) were developed and put into practice.
5. The case studies of industrial application of FDFDs prove their high efficiency and performance.
6. The industrial application of FDFDs is characterized by the vast geography of their usage and big range of forces for the forging presses, which these devices are fitted to.

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