УДК 621.791 https://doi.org/10.23947/1992-5980-2018-18-3-311-317

Repairing the main shaft of dryer toaster[*]

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Ремонт главного вала тостера сушилки[***]

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Introduction. The sources of damage and wear of the main shaft of the drier toaster are analyzed. The repair know-how and welding operations execution limitations which must be considered when developing the technique providing the restoration of the structure performance features are studied. The work objective is to develop a technique of repair without dismantling for the main toaster shaft. To solve the task, a design repair structure was installed, and postwelding operations that meet the engineering and regulatory requirements for this structure were performed.
Materials and Methods. In "Kompas 3D" software, the following models were developed: integral shaft (project shaft design); damaged shaft as a result of long-term operation (more than 15 years); and damaged shaft with a welded repair structure. Numerical simulation of the stress-strain state (SSS) was carried out.
Research Results. Software for the computational modeling of the repair structure SSS is developed. The repair shaft structure in which the maximum stresses do not exceed the shaft stresses in the project design is obtained using the model. To eliminate the aggressive medium effect on the corrosion fatigue strength of the shaft, an insulating method is used. A technique for mounting the repair structure to the shaft allowing for the outrun limitation 0.12 mm is developed.
Discussion and Conclusions. Torsion shafts damaged deeply by wear and corrosion are considered. To restore their structural integrity, it is worthwhile using the following complex of techniques:
— constructive (consists in the installation of optional parts that compensate for insufficient strength, and provides a reduction in stress concentration in the most loaded zones);
— processing (reduces residual welding stresses due to the reasonable sequence of deformation that contributes to generating favorable residual compressive stresses);
— isolation (is based on the application of anticorrosion coatings).

Введение. Статья посвящена анализу причин повреждений и износа главного вала тостера сушилки. Рассмотрены специфика ремонтного производства и ограничения в выполнении сварочных работ, которые необходимо учитывать при создании технологии, обеспечивающей восстановление эксплуатационных свойств конструкции.
Цель работы — создание технологии ремонта главного вала тостера без его разборки. Для реализации этой задачи была установлена расчетная ремонтная конструкция и выполнены послесварочные операции, обеспечивающие требования технической и нормативной документации к данной конструкции.
Материалы и методы. В программной среде «Компас 3D» разработаны модели: целого вала (конструкция вала в проектном состоянии); вала, поврежденного в результате длительной эксплуатации (более 15 лет); поврежденного вала с приваренной ремонтной конструкцией. Проведено численное моделирование напряженно-деформированного состояния (НДС) моделей.
Результаты исследования. Разработано программное обеспечение для численного моделирования НДС ремонтной конструкции. С помощью модели получена конструкция ремонтного вала, в которой максимальные напряжения не превышают напряжений вала в проектном состоянии. Для исключения влияния агрессивной среды на коррозионную усталостную прочность вала использован изоляционный способ. Для присоединения ремонтной конструкции к валу разработана технология выполнения швов, позволяющая ограничить биение 0,12 мм.
Обсуждение и заключения. Рассмотрены работающие при кручении валы, поврежденные в результате износа и коррозии на большую глубину. Для восстановления их конструктивной прочности целесообразно использовать комплекс перечисленных далее методов. Конструктивный (заключается в установке дополнительных деталей, компенсирующих недостаточную прочность, и обеспечивает уменьшение концентрации напряжений в наиболее нагруженных зонах). Технологический (уменьшает остаточные сварочные напряжения за счет рациональной последовательности деформирования, способствующего наведению благоприятных остаточных напряжений сжатия). Изоли-

[*] The research is done within the frame of Contract No. 130 of 19.04.2014.
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[***] Работа выполнена по договору № 130 от 19.04.2014 г.

The economic expediency of the developed repair technique is obvious. The repairing of the shaft without dismantling costs 180,000 rubles, while a new shaft costs 3.8 million rubles.

рующий (основан на нанесении антикоррозионных покрытий).
Экономическая целесообразность разработанной технологии ремонта несомненна. Ремонт вала без его разборки стоил 180 тысяч рублей, а цена нового вала — 3,8 млн рублей.

Keywords: welding repair under factory conditions, shaft repair, repair type selection, 3D modeling, finite-element method (FEM), optional parts, stress factor, repair technique, plastic deformation, economic expediency.

Ключевые слова: ремонт сваркой в производственных условиях, ремонт вала, выбор типа ремонта, 3D-моделирование, метод конечных элементов (МКЭ), дополнительные детали, концентрация напряжений, технология ремонта, пластическое деформирование, экономическая целесообразность.

For citation: Y.G. Lyudmirsky, S.S. Assaulenko. Repairing the main shaft of dryer toaster. Vestnik of DSTU, 2018, vol. 18, no.3, pp. 311−317. https://doi.org/10.23947/1992-5980-2018-18-3-311-317

Образец для цитирования: Людмирский, Ю. Г. Ремонт главного вала тостера сушилки / Ю. Г. Людмирский, С. С. Ассауленко // Вестник Дон. гос. техн. ун-та. — 2018. — Т. 18, № 3. — С. 311−317. https://doi.org/10.23947/1992-5980-2018-18-3-311-317

Introduction. Failure of machines is often due to the negative impact of structural, technological or operational factors. To choose the type of repair, you need to know:

— operational aspect features ,

— conditions of its operation;

— possible failure causes of the main elements.

The specificity of the repair is that you have to deal with already created structures during work performance. This requires the selection of certain welding methods, the location of repair welds, restricts access to welding sites. In some cases, the possibility of heating the metal during welding and subsequent heat treatment of the welded joint is reduced [1]. All this leads to the need for developing special technical solutions in each case.

Oil extraction plants for the distillation of solvent (gasoline) from the meal (cake) use an evaporator (toaster), equipped with heating jackets and steam supply pipelines. The toaster, shown in Fig. 1, is a column apparatus assembled from vats (1) mounted one above the other.

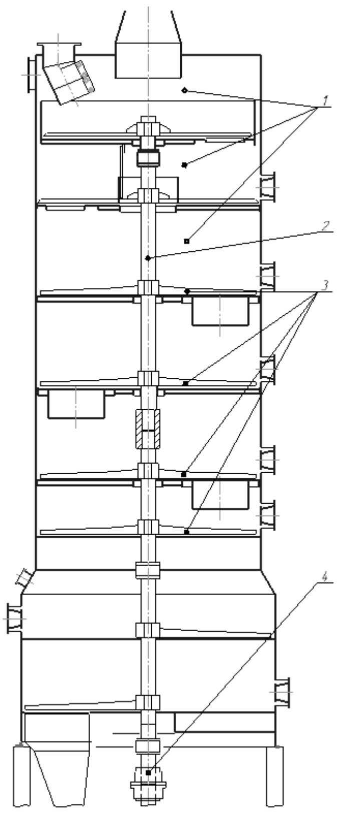


Fig 1. Scheme of dryer toaster

Through all the vats, shaft 2 passes, on which pair agitators of meal 3, installed above the bottoms of the vats with a small gap, are fixed. The shaft drive is provided through the reduction gear 4 of the engine capacity of 160 kW and rotates with a frequency of 10 Rev/min. Torque on the shaft of the toaster is 14500 kg•m.

Dryer toaster, investigated in the framework of this work, was in operation at the oil extraction plant of the "MEZ Yug Rusi" branch for 15 years, which led to significant local wear of the shaft.

The design dimensions of the shaft are as follows: diameter is 285 mm, length is 6860 mm. As the diagnostics had shown, the shaft wear was localized in the lower part, where it was in contact with the meal (acting as an abrasive). The temperature of the meal was 105 ^{o}C. The contact point was blown with moist air. In this part of the shaft at the site of 700 mm, its diameter decreased to 245 mm as a result of corrosion and mechanical wear.

The worn part of the shaft is shown in Fig. 2.

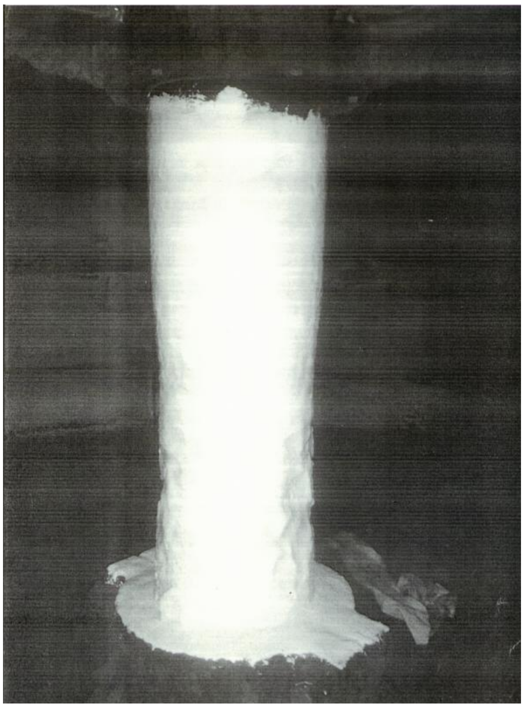


Fig. 2. Shaft wear after 15 years of operation

The calculations performed according to [2] showed that the polar moment of inertia of the shaft in the design was 6.6•10^4 cm^4, and due to the operation, it decreased to 3.8•10^4 cm^4. Further operation of the shaft without restoring its bearing capacity could lead to the destruction and explosion of gasoline vapor in the toaster. In this regard, various options for repair of the main shaft of the toaster were evaluated. Replacement was not considered due to the high cost of the individual shaft production. In addition, its dismantling required disassembly of the toaster and the room where it was installed, which was almost impossible.

Currently, the most widely used methods of repairing worn shafts are the following:

— welding metal over the damaged area [3] to restore the size and the carrying capacity of parts;

— replacement of the damaged section of the structure with a new one;

— installation of additional parts or structure repair [4].

The first repair option was rejected, because in this case it was required to weld a large amount of metal (more than 140 kg) on a vertically located shaft, which would inevitably lead to defects and large deformations.

The second method is difficult. In its implementation, there would be difficulties with cutting the damaged part off the shaft, cutting edges for welding, assembly and welding. This would result in unacceptable welding deformations. In this case, even with a successful replacement of the damaged area, the operational properties of the toaster would most probably be violated.

The third method is usually recommended for repair if the surface damage is large [4, 5]. Thus, it was decided to repair the main shaft of the toaster by installing a repair structure (Fig. 3).

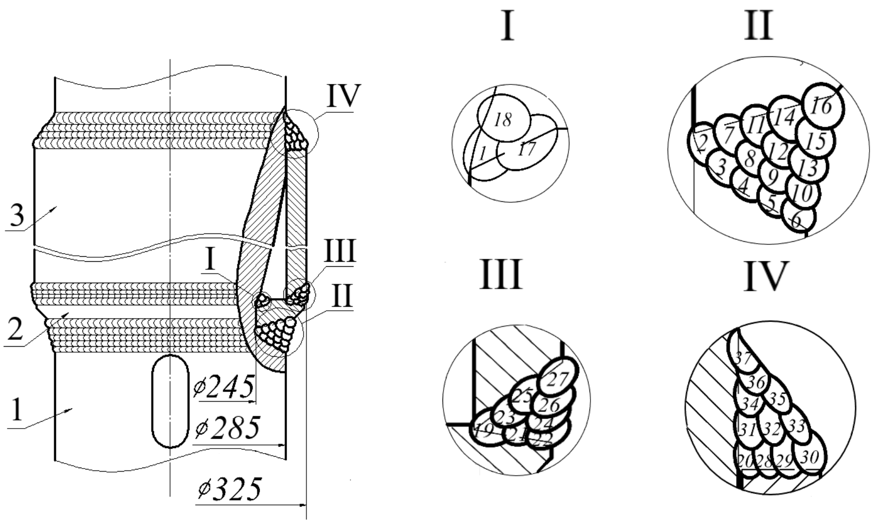


Fig 3. Scheme of repair structure

The design of the shaft 1 consists of two half-rings 2 and two half-couplings 3. The sizes of the coupling and the ring were determined according to strength and technological considerations. The length of the couplings equal to 800 mm, exceeded the length of the damaged section of the shaft by 100 mm. The inner couplings diameter is 285 mm, and the outer one is 325 mm. To restore the static strength of the shaft in its worn parts, it was needed to weld the element, the polar moment of inertia of which would make up for its wear loss ($6.6 \cdot 10^4$ cm^4 – $3.8 \cdot 10^4$ cm^4 = $2.8 \cdot 10^4$ cm^4). Then, the above-mentioned diameters of the polar moment of inertia of a coupling half is equal to $3.1 \cdot 10^4$ cm^4. Thus, the dimensions of the repair structure welded to the shaft not only restore the calculated moment of inertia of the shaft, but also increase it by 15 %, which provides static strength of the shaft.

The papers [6, 7, 8] show that the durability of the welded designs working at repeatedly static loadings in the damp environment, mainly depends on the stress-strain state (SSS) where weld metal comes to the basic metal. The finite element method (FEM) was used to estimate the effect of weld geometry on the SSS. When designing the repair structure, we sought to ensure that the stresses in the weld area did not exceed the stresses in the area of keyways on the shaft to transfer torque to the meal agitators.

The method of SSS calculation is presented in [9]. In the “Compass 3D” software environment, 3D-models of the complete shaft with the original keyway, damaged by the shaft corrosion, and the damaged shaft, were developed with account of the installation of the repair structure. The Ansys software product [10, 11] was used for the calculation. The 3D model was imported in Ansys Workbench. With the help of this software shell, pre-processing of geometry and selection of the material corresponding to the material of the shaft-17G1S was carried out (Table. 1).

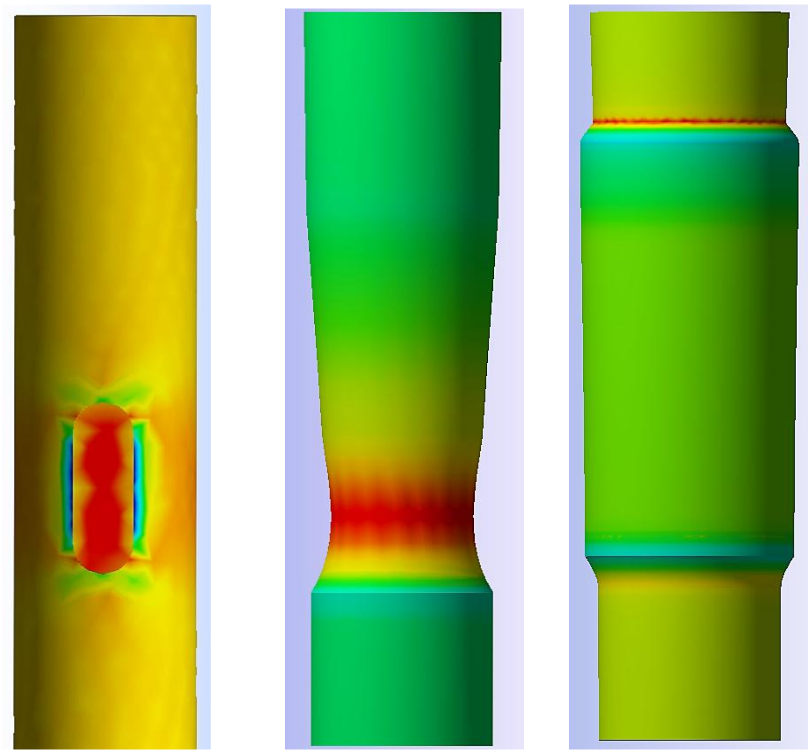
Table 1

Parameters of the selected material

Property	Unit of measurement	Value
Density	kg/m^3	7850
Yield stress	mPa	250
Ultimate tensile strength	mPa	460

Further, the calculation was carried out, which includes the creation of a finite element mesh, as well as the determination of boundary conditions by applying torque from the reducer and rigid fastening of the shaft on the reverse side.

Fig. 4 provides the results of the calculated structures, and Table 2 - maximum stresses on the shaft: in the areas of keyways (Fig. 4, a), in the place of shaft wear (Fig. 4, b), in the most loaded area of the repair design (Fig. 4, c).



a) *b*) *c*)

Fig. 4. Models of stress-strain state calculation in areas of: keyways (*a*); shaft corrosion (*b*); repair structure(*c*)

Table 2

Maximum calculated stresses

Area of stress calculation on the shaft	Maximum voltage, mPa
Keyways	74
Shaft corrosion	124
Repair structure	75

It can be seen that the stresses in the developed repair structure do not practically exceed the design stresses in the keyways areas.

SSS depends not only on the operating voltage, but also on the magnitude and the sign of residual stresses in the area of weld metal connection with the main metal. Therefore, the method of plastic deformation was used in the repair technology [12]. It allows you to reduce residual tensile stresses or even change them into favorable compressive stresses.

Before starting, degassing of the toaster and the shop where it was located was performed. The damaged part of the shaft and the welding site were cleaned with rotating brushes to the metallic sheen.

The assembly of the repair structure started with the installation of two half-rings 2 (see Fig. 3), their tightening up and tack welding. To weld the half-rings, the UONI electrodes 13/55 [13] were used in the modes specified in Table 3.

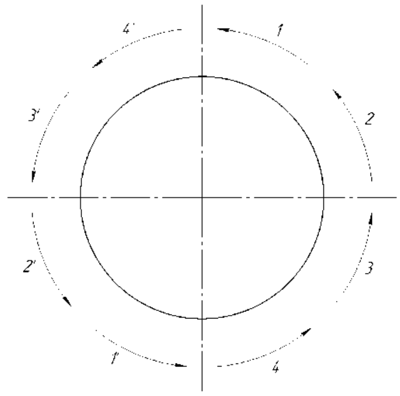
Table 3

Modes of manual arc welding with coated electrodes

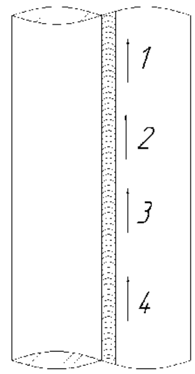
Electrode brand	Diameter, mm	Recommended current strength when AWM * A, in the position:		
		bottom	vertical	horizontal and ceiling
UONI 13/45, UONI 13/55	3.0	80–100	60–80	70–90
	4.0	130–160	100–130	120–140
	5.0	170–200	140–160	150–170
* AWM-arc welding mode.				

After that, the welds were cleaned flush with the base metal.

Then the ring was set perpendicular to the shaft, as shown in Fig. 3, and welded; circular welds were welded connecting the ring 2 to the shaft, according to the scheme shown in Fig. 5, a.



a)



b)

Fig. 5 Diagram of implementation of: circular welds (*a*), longitudinal welds (*b*)

The welding was performed simultaneously by two welders. The order of bead welding (1-18) is shown in Fig. 3.

Two coupling halves were assembled on the welded ring, so that the distance from the longitudinal welds of the ring to the longitudinal welds of the coupling was 120-130 mm. Half couplings were tightened around the shaft by the means of two centralizers; at each junction there were three tack welds with the length of 50-60 mm. To reduce the probability of occurrence of defects during welding, the beginning and the end of each tack weld was rubbed down with an abrasive tool. After this, the upper centralizer was removed, and the welding of longitudinal welds of the coupling started. The welding was performed by the step-back method [14] from the bottom up — in the order shown in Fig. 5, b. After performing 70 % of the length of the longitudinal weld, the lower centralizer was removed, and the root weld was completed. Filler and cap beads were done in the same order. Each subsequent layer was shifted relative to the previous one by 25-30 mm. The current strength recommended in Table 2 for vertical joints welding, was reduced by 10 %.

The circular welds connecting the coupling to the shaft and the ring were made simultaneously by two welders in diametrically opposite places relative to the shaft (see Fig. 5, a). First, the beads 19 to 27 and then, 28 to 37 (see Fig. 3) were welded. After circular welds were welded, their deseaming and plastic deformation at the edges of the weld metal with the base metal of the shaft was made. The quality of the welds was checked by the visual inspection in layers.

The radial-motion variation of the shaft was measured by hour-type indicators above the repair structure by 100 mm in two mutually perpendicular directions. Its value did not exceed 0.12 mm.

In order to protect the coupling and the shaft from corrosion, the space between them was filled with sunflower oil [15], and the outer surface of the shaft was insulated with epoxy glue of the EDP brand according to TS (technical specification) 07510508.90-94.

The integrity of the repaired shaft is monitored quarterly. It has been working reliably for four years with full compliance of functional indicators with the requirements of technical and regulatory documentation.

The economic feasibility of the developed technology is significant. The repair cost 180 thousand rubles, whereas the price of a new shaft is 3.8 million rubles.

Conclusions. To restore the structural strength of the shafts working in torsion, it is advisable to use a set of the following methods. The *constructive* method involves the installation of additional parts that compensates for the lack of strength, and provides a decrease in stress concentration in the most loaded areas. The *technological* method reduces residual welding stresses due to the rational sequence of deformation, which helps to induce favorable residual compression stresses. The *insulating* method is the application of anti-corrosion coatings.

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Received 22.05.2018
Submitted 23.05.2018
Scheduled in the issue 05.07.2018

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