STRESSES AND DEFORMATIONS IN THE SHREDDING SHAFTS OF A TWO-SHAFT SHREDDER FOR CRUSHING OF CONCRETE, RUBBER, PLASTIC AND WOOD

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ABSTRACT. The article focuses on stresses and deformations in the shredding shafts of a two-shaft shredder for concrete, rubber, plastic and wood crushing. A modeling study of the shredding shafts of such type of shredder has been performed in the present work. The studies of the mechanical load and behavior of the shredding shafts have been conducted through solving the equations describing the mechanical processes in working conditions under the finite element method. For this purpose a three-dimensional geometrical model of the shafts has been generated, which has been discretized (digitized) to a planned network of finite elements in the programming environment of ANSYS MECHANICAL APDL.

Keywords: stresses, deformations, two-shaft shredder.

НАПРЕЖЕНИЯ И ДЕФОРМАЦИИ В РАЗДРОБЯВАЩИТЕ ВАЛОВЕ НА ДВУВАЛОВ ШРЕДЕР ЗА РАЗДРОБЯВАНЕ НА БЕТОН, ГУМА, ПЛАСТМАСА И ДЪРВО

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РЕЗЮМЕ. Статията е посветена на изчисляване и проверка на раздробяващите валове на двувалов шредер за раздробяване на бетон, гума, пластмаса и дърво. Направено е моделно изследване на раздробяващите валове на такъв тип шредер. Изследванията на механичното натоварване и поведение на раздробяващите валове са проведени чрез решаване на уравненията, описващи механичните процеси при работни условия по метод на крайните елементи. За целта е генериран триизмерен геометричен модел на валовете, който е дискретизиран на планирана мрежа от крайни елементи в програмната среда на ANSYS MECHANICAL APDL.

Ключови думи: напрежения, деформации, двувалов шредер.

Introduction

The continuous process of production and use of products from rubber, plastic, and the intensified construction lead to a serious accumulation of waste, imbalance, and danger for the environment. In all industrial societies, the need appears for reducing the household and technogenic waste and their re-integration in the production process. As a process, the recycling of construction waste, as well as waste from rubber, plastic and wood, is extremely important both for the environment and the society.

The development of the recycling industry sees an increasing need for crushed materials with different composition and characteristics. The creation of new structures of crushing machines and their study through adequate mechanical and mathematical models, their engineering design, and their practical realization are a topical scientific problem (Vatskicheva, 2017).

The shredders are a relatively new group of machines, crushing refuse utility and waste materials. According to the number of the operating shafts, the shredders are classified intos single-shaft, two-shaft and four-shaft ones (Abadzhiev and Tonkov, 2007). Shredders are configured according to each unique application, with the selection of different thicknesses and number of the cutting teeth, diameter of the shaft, thickness of the distance bushings, power of drive, and production capacity.

According to the technology of crushing, there is a choice between single-shaft, two-shaft, three-shaft, four-shaft, five-shaft shredders, with a different level of automation and control of the basic parameters, different noise level, different speed of rotation, supply, degree of sealing (pressurization), etc. (Abadzhiev and Tonkov, 2007).

The advantage of the two-shaft shredders is their high productive capacity. The disadvantages are related to the high price and the high maintenance cost of the machines.

The two-shaft hydraulic shredder consists of a feeder-conveyor, a receiving hopper, a crushing chamber, an output strip, an unloading strip, and a strip for the separation of metal particles.

In the present work, a model survey is carried out of the shredding shafts of such type of shredder for crushing of concrete waste.

Object of study

The object of study in the present development is the mechanical load and behavior of the shredding shafts of a two-shaft shredder for crushing of concrete, rubber, plastic and wood.

The shredding shafts are parallel, with length 900 mm, axle base 350 mm, and hexagonal cross-section. The crushing disks are mounted on the shafts. Between the disks, to the housing of the chamber, there are mounted counter-knives, serving for cleaning the space between the separate disks (Fig.1).

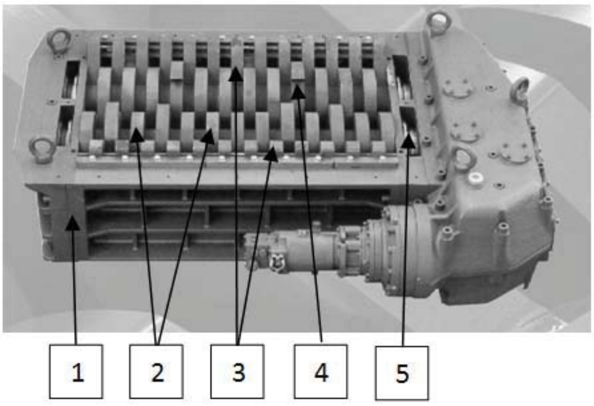

Fig.1. Shredding shafts
Legend: (1) Housing; (2) Crushing disks; (3) Counter-knives; (4) Removable cone; (5) Openings between the reducer and the crushing chamber

The disks intended for crushing are double-topped (two-pointed). On each top is mounted a removable cone (4) of tungsten carbide with a hardness HRC 60 - 64. The pressure exerted by the cone on the concrete must exceed the compressive strength of the concrete, which is 55 MPa. The excess or shortage of power for crushing is regulated through change of the number of simultaneously operating disks and the number of tops on each disk. In case of re-dimensioning of the drive it is possible to increase the crushing disks from two to three, with which the productive capacity will increase by about 50%.

Both crushing shafts are mounted in a common housing (1) by radial axial and radial roller bearings (Borshtev et al., 2000). The protection of the bearing units is three-stage:

- the first stage is through openings (5) between the reducer (reduction gear) and the crushing chamber. The powder and the particles, having penetrated on the side of the shafts, fall through the openings;
- the second stage is through double elastic sealants of the shafts axis;
- the third stage is through the lubrication of the bearings with oil under low pressure (3-5 bar), counteracting the penetration of particles into the bearing unit.

Drive (actuation) of the shredding shafts

The power W required for the propelling of the shredding shafts is determined on the basis of the formula:

$$W = \frac{P_b \cdot \mu . S_t \frac{D_t}{2} . Z . N_v}{9554} = \frac{55.10^5 .2.6.10^{-4} .0{,}15.8.25}{9554} = 207\ kW;$$

where:
P_b is the stress for the destruction of the concrete of the cross-ties - 55 MPa;
S_t is the maximum contact area of each destructive tooth ~20 x 30 mm or $6x10^{-4}$ m^2;
Z is the number of simultaneously operating disks: 8 (4 from one of the shafts and 4 from the other shaft) with a total length along the axis of the shafts of 320 mm, which is greater than the maximum dimension of the cross-ties - 300 mm;
D_t is the diameter of the cutting disks: 300 mm (the distance of the teeth from the shaft axis);
N_v is the revolutions of the shafts: 25 min^{-1};
μ is the coefficient of reserve of power, which is equal to 2.

The shredding shafts are mounted on the side of the reducers in paired roller radial axial bearings, and on the other side – in a needle-roller bearing with an inner ring (Borshtev, 2004).

The structure of the shredding shafts is verified for total strength /tension, compression, torsion/. Applied are the loads from the weight of the shaft, the knives with the destructive teeth, and the intermediate disks, as well as the support reactions in the bearings of the shafts. The studies have been conducted through the mathematical models and thenumerical procedures described below.

Model study concept

The studies of the mechanical load and behavior of the shredding shafts have been conducted by solving the equations that describe the mechanical processes in working conditions by the method of the finite elements (FAG Spherical roller bearings E1, 2011). For this purpose, a three-dimensional geometric model of the lower part (underpart) of the chamber has been generated. The model is discretized to a planned network of finite elements in the programming environment of ANSYS MECHANICAL APDL.

The end conditions, reflecting the mechanical load during the operation of the steel structure, include the following parameters (Tavakoli et al., 2008):

- input power: P_{ip} = 90 кW;
- revolutions of the working shaft: n_V= 25 min^{-1};
- frequency of rotation of the working shaft:

$$\omega_V = \frac{\pi . n_V}{30} = 2{,}62\ rad/s;$$

- torque of the working shaft:

$$M_V = \frac{P_{ip}}{\omega_V \eta} = 35\ kNm,$$

where η=0,98 is the efficiency of the transmission;
- stress of destruction of the concrete: t_s = 55 MPa;
- shear force from one knife:

$$F_S = \frac{M_V}{3.0{,}175} = 66{,}7\ kN,$$

- moment of resistance of the crushing from one knife:

$$M_{S2} = F_S . l_s = 11{,}67\ kNm.$$

The pressure that each carbide cone on the disk teeth exerts on the destructed railway sleeper is 94 MPa, which is nearly 2 times higher than the stress of destruction of 55 MPa. The disruptive pressure has been adopted as applied on an area of the tooth with a diameter of 30 mm. It is transformed into radial forces on the knives, respectively torques, on the shafts of the shredder. The condition is accepted about three simultaneously working "destructive" teeth. The nominal moment of rotation of each shaft for 25 rpm is determined: 40 kNm. In this case, the appropriate heliocentric-type reducer (reduction gear) is PG 5001 with gear ratio i = 5.1. Accordingly, the driving hydraulic motor is a radial piston with constant flow, of the type IAM 1600 H, with maximum revolutions (turnovers) 250 min^{-1}, and a moment of rotation equal to 7860 Nm at a pressure of 300 bar.

The mechanical load during operation of the structure is presented in Fig. 2.

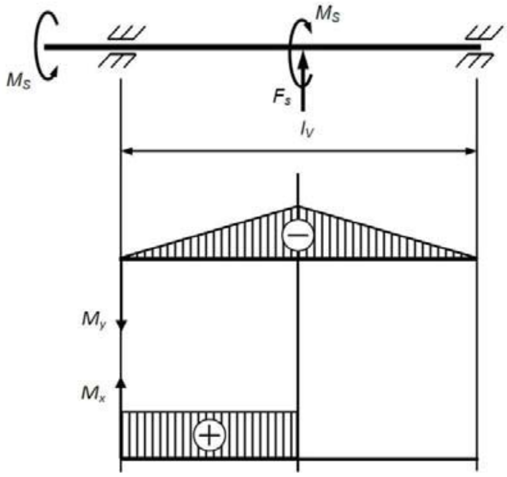

Fig. 2. Load

The system of equations has been solved with the parameters of the steel presented in Table 1.

Numerical results

The data for the material of the shafts accepted in the verification is summarized in Table 1.

Table 1.
Strength characteristics of the material for the shredding shafts

Name	Steel 42CrMo4	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	210 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	80.7692 GPa
Stress Thermal	Expansion Coefficient	0.000012 ul/c
	Thermal Conductivity	56 W/(m K)
	Specific Heat	460 J/(kg c)

The figures below present a visualization of basic parameters characterizing the state of stress of the steel structure.

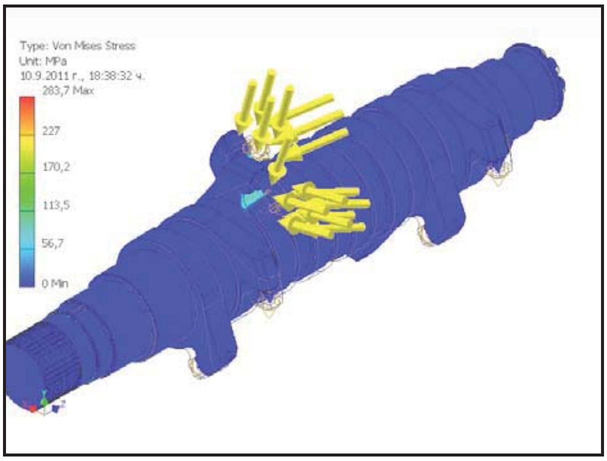

Fig. 3. Maximum stresses in the elements of the shaft

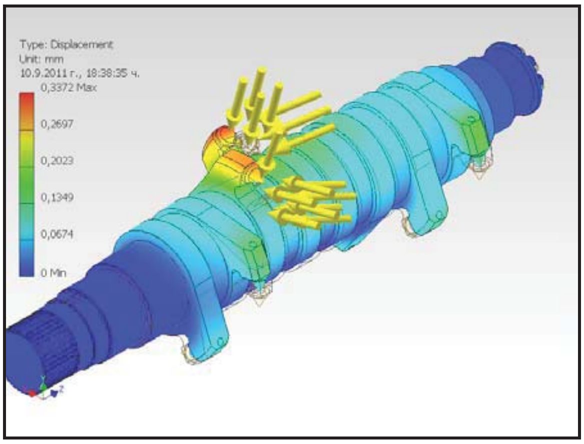

Fig. 4. Maximum deformations of the elements of the shaft

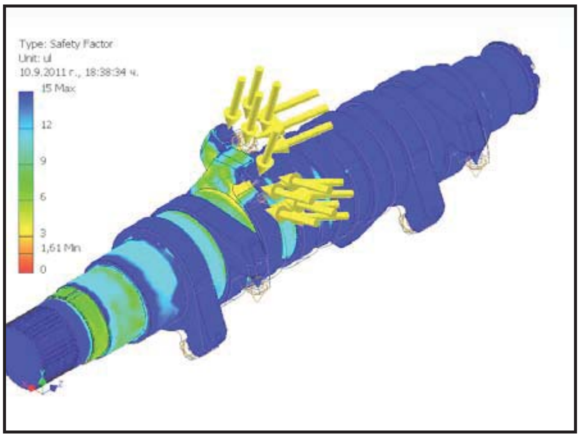

Fig. 5. Calculated safety factor for the elements of the shaft

Table 2.
Support reactions

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Pin Constraint:1	90793.,5 N	-90786.3 N	5917 N m	-73.9095 N m
		-1143.34 N		-5916.54 N m
		0 N		0 N m
Pin Constraint:2	0 N	0 N	4082.63 N m	-182.663 N m
		0 N		-4078.55 N m
		0 N		0 N m
Pin Constraint:3	49891.2 N	-49522.2 N	12149.7 N m	1378.84 N m
		6057.02 N		12071.2 N m
		0 N		0 N m
Pin Constraint:4	20872.4 N	20871.4 N	16536.2 N m	-21.0458 N m
		-207.16 N		238.686 N m
		0 N		16534,4 N m

Table 3 summarizes the maximum and minimum stresses and deformations.

Table 3.
Summarized stresses and deformations

Name	Minimum	Maximum
Volume	39292300 mm^3	
Mass	308.444 kg	
Von Mises Stress	0.00548071 MPa	65.7722 MPa
1st Principal Stress	-15.6595 MPa	28.8686 MPa
3rd Principal Stress	-83.2857 MPa	4.36874 MPa
Displacement	0 mm	0.127705 mm
Safety Factor	3.14722	15

The conducted study shows that the maximum stresses for the examined structure do not exceed the permissible values for the material of the shafts.

Conclusions

The results from the conducted model studies provide the basis for the following conclusions:

- A 3D model of the shredding shafts of a shredder for concrete railway sleeper is constructed;
- A power model of the load of the shaft from the technological forces during crushing is developed;
- The stresses and the deformations in the system shaft – knives – carbide teeth are studied;
- The coefficient of mechanical safety for the maximum load of the shafts of the shredder is determined;
- The mechanical reliability of the shafts is demonstrated;
- A suitable drive of each shredding shaft is selected – the heliocentric-type of reducer and the radial hydraulic motor.

The studied structure of shredding shafts may be used for the shredder-type of crushing machines.

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