IOP Conf. Series: Materials Science and Engineering **327** (2018) 042026 doi:10.1088/1757-899X/327/4/042026

Studying quick coupler efficiency in working attachment system of single-bucket power shovel

E V Duganova, N A Zagorodniy, D N Solodovnikov, A S Korneyev

Belgorod State Technological University named after. V.G. Shouhov, 308012, Russia, Belgorod, Kostyukov St., 46.

E-mail: crumb1202@mail.ru

Abstract A prototype of a quick-disconnect connector (quick coupler) with an unloaded retention mechanism was developed from the analysis of typical quick couplers used as intermediate elements for power shovels of different manufacturers. A method is presented, allowing building a simulation model of the quick coupler prototype as an alternative to physical modeling for further studies.

1. Introduction

Road building and construction processes include a list of diverse sequential operations, requiring work attachments of an optimized design. This issue is being resolved by leading manufacturers of the road building and construction machinery by extending the range of the work attachments which may be used with the basic machine. Such multi-functionality is implemented by means of quick couplers, providing an operator of the machine with a possibility to exchange the work tool quickly and conveniently.

Diversity of designs of existing quick couplers, lack of grounded recommendations for their effective application with confirmed parameters of compatibility with the work tool, influence of this additional link introduced into the design of the work tool onto the technical and economic characteristics of the equipment, insufficient development in the area of work tool reliability when used with a quick coupler – all these facts allow assuming that creating a method for design and improvement of quick couplers and substantiation of their modes of operation is a timely scientific and practical task.

To evaluate designs of the quick couplers and reveal their possible functional limitation, the classical studies recommend creating a physical model. Currently, development of a prototype, not to speak of full-scale testing with diverse operational tasks, is not only a material-intensive process, but a costly one as well. At the same time, the modern digital technologies and software packages allow performing a computer simulation and establishing functional parameters which are as close as possible to the actual ones, as well as evaluating the design under heavy load and different unlikely conditions. [1]

There is a number of software packages, developed on the basis of the finite element method (FEM): ANSIS, NASTRAN, COSMOSSpress, APM WinMachine, SolidWorks. Analysis of these packages has shown that in comparison with other similar systems, SolidWorks has the most developed possibilities to create and edit surfaces, as well as for joint treatment of surfaces and solid bodies. [2].

When solving a task with non-linear elements, it is necessary to determine an iteration algorithm for solution of a system of non-linear equations when applying a load. Two algorithms are most popular: Newton-Raphson and Modified Newton-Raphson.

Figure 1: Geometric models of a working attachment with a hydrohammer, grab bucket, hydraulic shear.

The computer simulation used the geometric parameters of a US 5382110 quick coupler [3, 4].

The modern digital technologies and software packages allow performing computer simulation and establishing functional parameters, which are as close as possible to the real parameters, as well as evaluating the design under heavy load and different unlikely conditions.

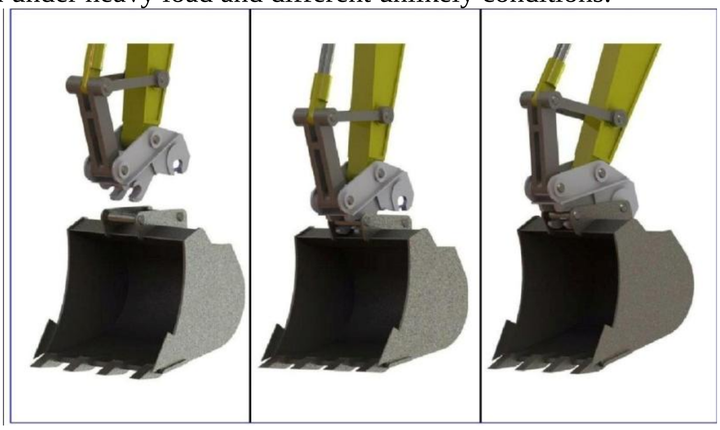


Figure 2. The simulated process of connecting a dipper and a bucket in a developed prototype

The studies are based on adapting a standard method of multi-stage modeling of dynamic loads for the "dipper - quick coupler - work tool" system, thus allowing creating a variable-based model of the basic machine functioning, with considerations for such factors as operating conditions, a type of soil (material) being treated, a task completion period, equipment life, a type of the process operation.

2. Simulation of a «Handle – Quick Coupler – Work Tool» system

The task of the designer is to create such work tool or working attachment that meets the requirements for strength and rigidity, is reliable in operation, durable and has less metal intensity and better technical parameters than previous designs.

At the first stage of the design, a principal configuration of the element, ways of its fixation to the equipment's parts are determined; very tentative preliminary values of dimensions and a cross-section form are given depending on the operating conditions of the element as a part of the machinery, external load, process, labor intensity. At the second stage of the design, an evaluation of the element's deflected mode is performed, its strength parameters are determined, form and dimensions undergo corrections. A degree of accuracy, to which the actual strength is approached and the rational design is created, largely depends on the correct selection of the computational pattern. The latter chooses the most viable features of the equipment, discarding the structural (non-working) elements, while the design and its fixation to the parts of the equipment are idealized.

Analysis of the computational patterns is performed with the general methods of structural engineering, which allow evaluating a statistically indeterminate form of a frame structure, determining stresses and displacements in predefined locations of the structure, finding regularities in the computational pattern, which correspond to the actual structure. The design of machines is calculated for an elastic strain range of the metal; at that, the design elements are linear solids. The number of links in a statically determinate system is equal to three (derived from the number of main static equations of planar systems). If the number of links exceeds three, the systems are statically indeterminate. The latter also include systems with closed loops, where stresses in the elements cannot be found out with only static equations. The number of excessive links *L*, determining a degree of static indetermination of a system, consisting of $Д$ elements is found using the formula [1]:

$$L = 2Sh + C_0 - 3D, \tag{1}$$

where $2Sh + C_0 -$ the number of links in the system; $3D -$ the number of required links.

The «dipper - quick coupler - work tool» system is statically indeterminate. Due to the presence of excessive links in the statically indeterminate systems, there are obstacles for free displacement of nodes.

The displacement in any predefined point of the system due to action of a load is usually determined with the More's formula, derived from Betti's reciprocal theorem and Hooke's law.

The procedure to determine the displacement is as follows:

1. For a predefined system, a diagram of internal force (moment M_P, normal N_P and lateral Q_P forces) depending on load is plotted.

2. A so-called fictitious state of the system is considered, when the point, whose displacement is to be determined, is subjected to single force $P_i = 1$ in the direction of the sought displacement. If a rotational angle needs to be determined in a certain section, a unit moment is applied $M_i = 1$.

3. Diagrams M_i, N_i, Q_i are plotted, reflecting actions of the unit forces.

4. The More's formula is used to calculate the sought displacement:

$$\Delta_i = \sum\int_0^s \frac{M_i M_P ds}{EJ} + \sum\int_0^s \frac{N_i N_P ds}{EF} + \sum\int_0^s \frac{kQ_i Q_P ds}{GF}. \tag{2}$$

Forces in the elements of the statically indeterminate systems depend on loads, changes in temperature, movement of supports, imperfections of assembly, geometric dimensions of both the structure as a whole and its cross-sections; they also depend on physical properties of the construction materials. The principal methods for the statically indeterminate systems engineering are a force method and a deformation method (also known as a displacement method).

The next step in the design is moving from the internal forces obtained to stress values acting in the most dangerous cross-sections of the design. These stress values are obtained by the relevant formulas for strength of materials. The obtained calculated stress values, corresponding to the least advantageous loading of the structure, are then compared to those allowed for the element. The allowable stress values $[\sigma]$ are obtained by dividing the critical stress of the material by the factor of safety n.

For steels employed in the design of construction and road building machinery, the critical stress showing that the bearing strength of the material is depleted (when calculating for the elastic zone) is yield stress σ_τ. The stresses are checked with the formulas:

$$\sigma \le [\sigma]; \ \tau \le [\tau],$$

where σ and $\tau -$ calculated normal and tangent stresses; $[\sigma]$ and $[\tau]$ are allowable normal and tangent stress under the action of a static load.

Computer simulation of the «dipper - adapter - work tool» system with the use of different types of replaceable work tool allows assessing and comparing action of the dynamic loads onto the quick coupler [5].

When designing a new machine, these dependencies may be used to obtain initial technical parameters of weight *m*, capacity *N*, bucket capacity *q* and others, depending on operating conditions, which are stated in the design assignment under the traditional methods of design.

Correct determination of loads onto the element of the working attachment of the power shovel and determination of safety factors influence the operational capability of the design, its reliability and weight, as well as energy consumption of the working process. It is known that in most of the power shovels, currently produced, about 70% of energy consumed in the back-hoe boom-raising mechanism is consumed to raise the work tool itself, and only about 30% is consumed to raise the soil in the bucket. The power shovel is a dynamic machine, so acceleration or deceleration of the turntable complete with the working attachment is a characteristic part of its working cycle. Thus, minimizing the weight of the working attachment and energy consumption of cyclic operations is a current task.

The power shovel's working attachment allows performing several independent movements: boom rotation with respect to the platform, dipper rotation with respect to the boom, bucket rotation with respect to the dipper. In more complex attachment systems, the number of degrees of freedom may exceed three, making spacial manipulation with the working attachment possible. A bucket stop against an unsurmountable obstacle may happen at different positions of the working attachment's elements. At that, depending on the position, the arms of forces, action lines and their value, all undergo changes. Independent motions may result in an infinite number of different positions of the attachment's elements in space [6].

The issues with selection of the computational patterns and loads combinations to perform strength calculations with a larger degree of confidence are defined by the following causes:

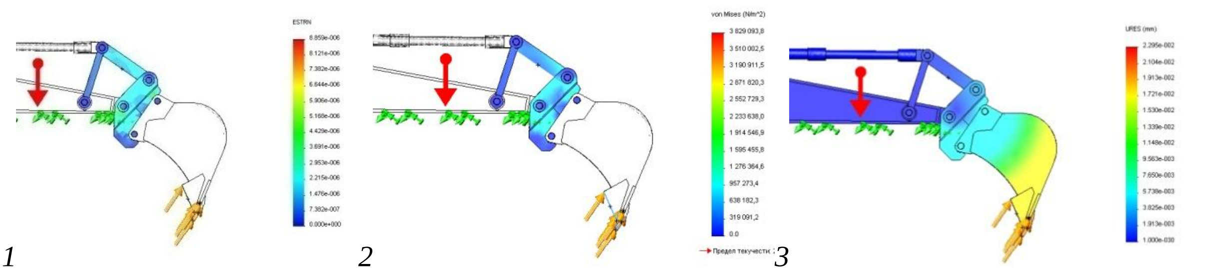
• stresses in the elements of the working attachment depend on the magnitude and direction of external forces and on positional relationship between the elements;

• the main external load onto the working attachment is a resistance to the cutting edge displacement, which is the highest when the bucket meets an unsurmountable obstacle and it may be directed at any angle to the direction of the cutting edge movement. The value of this load depends on its direction;

• maximum stresses in different elements and even in different cross sections of the same elements do not appear simultaneously;

• the number of positions of the working attachments and loads may easily reach several thousands (when defined as a number or combinations of boom inclination, dipper inclination, bucket angle and load with all the angles being changed at a step of 20°) [6].

Figure 3 shows the process of determining deformation, stress and displacement: the boom is in the lowest position, the dipper is turned maximally outwards, the digging force is against an unsurmountable obstacle. In this position, no factors are active that limit the digging force at the bucket's cutting edge.



1 *2* *3*

Figure 3. Determining static deformation (*1*), static stress (*2*), static displacement (*3*) in the «dipper - quick coupler - bucket» system

3. Determining a strain-stress state of the quick coupler body.

Engineering calculations for the quick coupler are performed for vertical loads corresponding a weight of the bucket with the volume of 0.65 m^3, 0.77 m^3 and 1 m^3 full of soil. The forces were applied to the pins that secure the bucket (Figure 4). For the 0.65 m^3 bucket the load is 1.17 tonnes, for the 0.77 m^3 bucket, it is 13.8 tonnes and for the 1 m^3 one – 18 tonnes.

The body of the quick coupler is manufactured of 09G2S steel. Figure 4 shows the points where the loads are localized and applied to the quick coupler's body. [7]

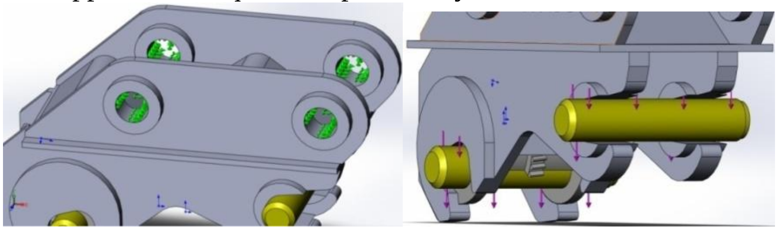
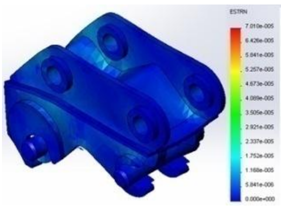
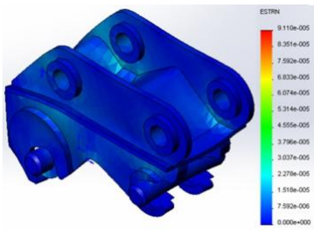
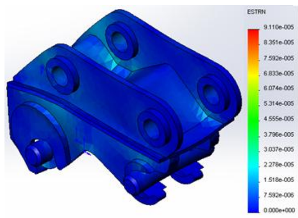


Figure 4. Points of localization and application of the quick coupler loads

The modeled coupler was used for calculations of equivalent deformation, stress and displacement.

Table 1 contains the stress and deformation map of the quick coupler after its testing for fatigue stress under operational loads.

Table 1. Deformations of the quick coupler with different volume of the bucket

Bucket volume, m^3	0.65	0.77	1
Load, *t*	1.17	1.386	1.8
Maximum deformation, nm	50.5	70	91.1
Deformation map			

The maximum deformation value of 91.1 nm is seen when using the bucket with the volume of 1 m^3. The minimum value is seen when the bucket of 0.65 m^3 is used, it amounts to 50.5 nm.

Stresses and displacements inside the body of the quick coupler are calculated similarly for operations with different volume of the buckets.

4. Conclusion

The developed computer model of the quick coupler and performed design calculations allow reducing the research costs by proposing a calculation method for measurement of changes in the effective parameters of the basic machine when an additional element is introduced to extend the machine's functionality by increasing the range of the working attachments used; it allows solving the issue of complex mechanization of construction works using the principle of a "single vehicle fleet".

The performed calculations allow concluding that all the parameters do not go outside the allowable limits, the quick coupler and pins sustain the loads stated by the manufacturer for this type of buckets.

The algorithm has been developed and used to simulate the prototype of a quick-release connector as an element of the working attachment of a power shovel in the "dipper – quick coupler – working tool" system.

The method to build the simulation model of the dipper - quick coupler - working tool" system for use with different types of the replaceable working tools allows assessing and comparing action of loads onto the quick coupler and lowering both material and labor costs of the experimental research.

5. Acknowledgment
The article was prepared within the development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shoukhov, using equipment of High Technology Center at BSTU named after V.G. Shukhov.

References
[1] Prokhorova E V, Sevryugina N S 2013 *Annals of the Belgorod State Technological University named after V.G. Shoukhov* **2** 192-195
[2] Alyamovsky A A, Sobachkin A A, Odintsov E V, Kharitonovitch A A, Ponomarev N B 2005 *SolidWorks. Computer Modeling in Practical Engineering*. (Saint Petersburg: BHV-Peterburg)
[3] Richard D. Perotto, Terry L. Briscoe, Christopher M. Carpenter, Dean F. Richards 1995 *Patent - 5382110 US, IPC E02F 3/413. Quick coupling device. ESCO Corporation, Portland, Oreg. - no.998671; Application 30.12.1992; Published 17.01.1995.*
[4] Herman J, Maurer J I 1981 *Patent - 4373852 US Case Company, Racine, Wis. - no. 280654; Application 06.07.1981; Published 15.02.1983*
[5] Prokhorova E V, Sevryugina N S, Volkov E A 2013 *SDM* **8** 7-10
[6] Pavlov V P 2007 *CAD and graphics* **2** 78-81