CAE-JUSTIFICATION OF THE LEADING SHAFT OF THE TEST STAND

Alexander PASTUKHOV[1], Evgeny TIMASHOV[2], Olga SHARAYA[1], Dmitry BAKHAREV[1]

[1]*Belgorod State Agricultural University named after V. Gorin, Russian Federation*
[2]*Belgorod University of Cooperation, Economics and Law, Russian Federation*

Abstract
For assessment of reliability of power knots of transmissions of transport and technological machines, for example, of drive lines, on the basis of resource tests develop special stands which provide realization of service conditions. Purpose - ensuring durability and rigidity of the leading shaft of the stand of the power circuit bearing the leading elements: technological conical tooth gear and the tested cardan joint. The analysis of durability and rigidity has shown that statically definable scheme of shaft does not provide the required working capacity level. Statically indefinable scheme of the leading shaft of power circuit is offered. Justification of design of shaft and test calculations are executed on the basis of CAE-technologies in APM WinMachine with use of the WinShaft module. As a result on the normal tension, reserve factor and deformation of shaft the provision of intermediate bearing part is proved, the operability - is provided.

Key words: *power circuit; tests; resource; durability; rigidity.*

INTRODUCTION

Due to the expansion of scope of products of agricultural mechanical engineering and complication of the equipment the importance of problem of reliability of modern machines continuously increases. At all stages of life cycle of products, including "scientific research – design – production – operation", definition of indicators of reliability includes complex of works on establishment of quantitative values, and control – assessment of compliance of the reached reliability level to regulatory requirements (*Lamberson L.R., Kapur K.S., 2009*). To definition and confirmation of indicators of reliability at development stage of skilled copies and assessment of quality of the repaired products apply experimental methods, in particular, research resource stand tests. The technical instrument of stand tests is the stand equipment which is the technical device for reproduction of conditions of loading and functioning in operation (*Velichkin I.N., 1999; Kljatis L.M., Khabatov B.Sh., 1990*). At assessment of reliability of power knots of the farm vehicles losing the working capacity because of wear and fatigue for the purpose of obtaining reliable information apply stand resource tests of products in the form of the accelerated tests by toughening of loading or sealing on time at the same time obtain information on reliability of object in shorter terms, than in operation (*Srivastava A.K., et al. 2006; Flick E.P., 1984; Timashov E.P., Pastukhov A.G., 2009*). For load-bearing parts of the stand of loading, created at tests are limit therefore the question of design of the stand and justification of durability and rigidity of its elements is very difficult and relevant. At experimental working off of design of the stand for tests of drive lines (*RU 2134412*) the weak point - the leading shaft is revealed (*Erokhin M.N., Pastukhov A.G., 2008; Pastukhov A.G., 2008*). The initial sizes of the leading shaft have been established on the basis of static calculation on bend with torsion on equivalent tension, however the specified calculation for reserve factor on fatigue strength, shows about violation of condition of strength (*Pastukhov A.G., et al., 2018 a*). The aim of the study – ensuring durability and rigidity of design of the leading shaft by justification of the settlement scheme on the basis of CAE-technology.

MATERIALS AND METHODS

In practice of development of the stand equipment for experimental assessment of durability of drive lines there are three kinds of configuration of power circuit: 1) the direct-flow power scheme - short circuit of power circuit is carried out by frame; 2) the consecutive arrangement of the technological and experienced drives in power circuit – short circuit of power circuit is carried out by the mentioned drives; 3) parallel arrangement of the technological and experienced drives in power circuit – power short circuit by coverage technological drive of the experienced drive. Main shortcomings of schemes of configuration, respectively: 1) level of loading of the experienced drive depends on the power of the

established power source (electric motor); 2) equal loading both the technological, and experienced drives; 3) increased requirements of durability and rigidity to the bearing system of drive gear. Advantages of the provided schemes are obvious, respectively: 1) simplicity of design; 2) universality of design; 3) low loading of technological drive due to seating on the bigger radius of rotation. Thus, stands of the third scheme of configuration are perspective in terms of carrying out resource tests of power elements of transmissions, for example, of drive lines (*Erokhin M.N., Pastukhov A.G., 2008*).
The stand (*RU 2134412*) is developed for resource tests of drive lines taking into account influence of dynamic loads from toothed gearings, which contains electric motor 1, by means of elastic clutch 2 connected to technological gear reducer 3, the tested drive line 4 and the loading device 5, included in power circuit, reduction ratio of reducer 3 is equal to unit, and tooth gears of 6 and 7 conical reducers 3 are established on conducted 8 and the leading 9 shaft located in bearing parts 10 (Fig. 1).

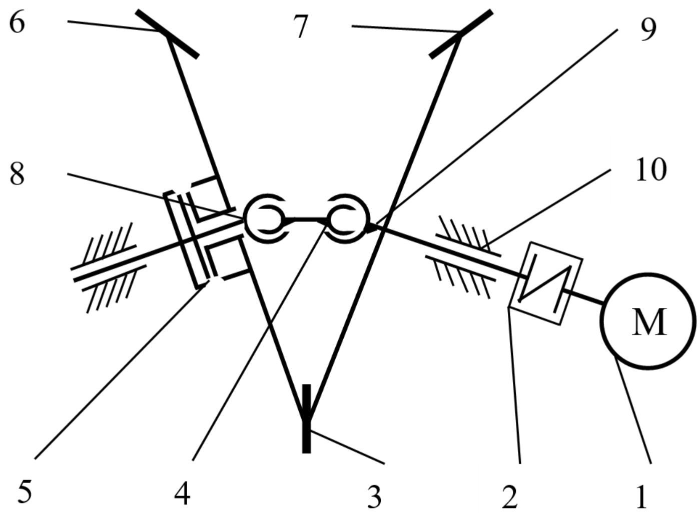

Fig. 1 The kinematic scheme of the stand for test of drive lines

In the course of practical working off of test procedure at the stand it is revealed that considerable conveyance of the end of the leading shaft 9 where the leading tooth gear 7 is established, leads to sidesway in gear reducer 3 that has an adverse effect on providing spot of contact piece in gear gearing. Thus, selection of geometrical characteristics of shaft 8 and 9 under the terms of durability and rigidity does not provide conditions of operability of technological drive. In this regard the hypothesis of introduction of static indefinability in the scheme of installation of the leading shaft is made for what it is necessary to define the provision of additional bearing part.
Due to the invariancy and high labor input of analytical calculations as the settlement tool the program complex of engineering calculations APM WinMashine (STC «Automated Design of Mashines», Russia, Korolyev), in particular, the WinShaft module - is applied to calculation of shaft on durability and rigidity (*Shelofast V.V., et al., 2013; Pastukhov A.G., et al., 2018 b*).
The course of preparation and carrying out calculations contains the following stages: 1) drawing up three settlement schemes of configuration of the leading shaft: statically definable scheme of shaft (Fig. 2), statically indefinable scheme with additional bearing part on the end of shaft (Fig. 3), statically indefinable scheme with additional bearing part of swing on the established ring gear of technological wheels of conical reducer (Fig. 4); 2) establishment of constructive technology factors of design of shaft and the application of loadings from the technological toothed gearing; 3) calculation of values of reserve factor on fatigue strength of n_{fat}, equivalent normal tension σ_{eq} and conveyances of f in 100 sections of shaft on length with the analysis of the 1st own form of deformation of shaft.
On Fig. 2-4 sketch of shaft, constructive and technological elements and coordinates of arrangement of bearing parts are shown full-scale on large-scale sex of the graphic editor of the module. In protocols of calculation numerical values of the calculated sizes and their graphic interpretation are recorded.
As basic data are accepted: nominal torque in power circuit is T_{nom}=600 (Nm), average dividing diameter of tooth gears is d_m=255 (mm), cog cross-section corner is α=20(°), corner of dividing cone of wheel is δ=81(°), district force in gearing is F_t=4706 (N), radial force is F_r=267 (N), axial force is F_a=1692 (N); subject to test is cardan joints IV of standard size on RD 37.001.665-96 with bearings GPZ-804704K5.

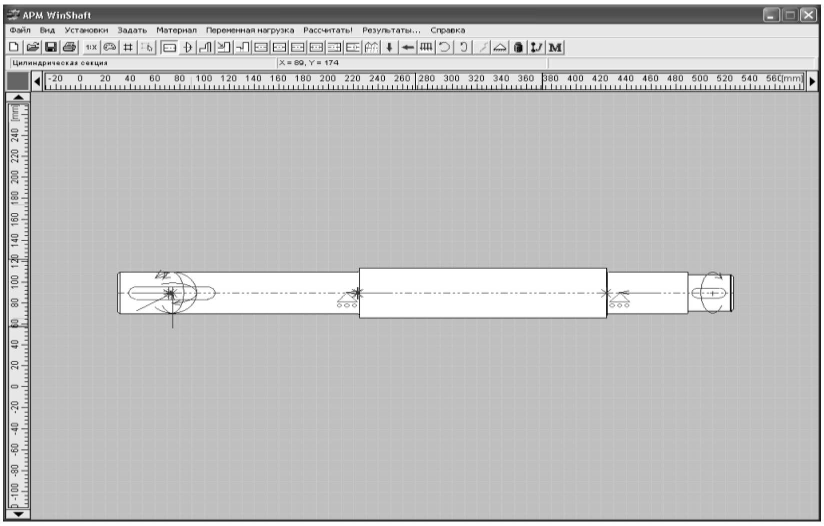

Fig. 2 Settlement scheme of statically definable leading shaft (option 1)

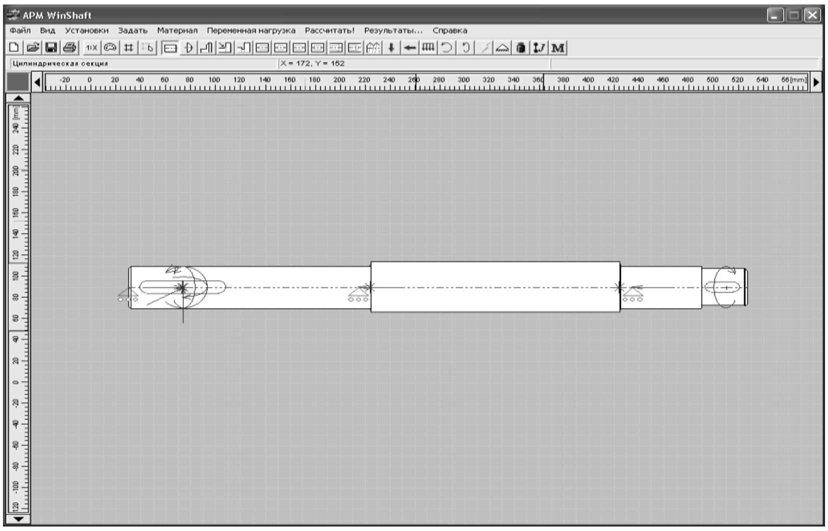

Fig. 3 Settlement scheme of statically indefinable leading shaft (option 2)

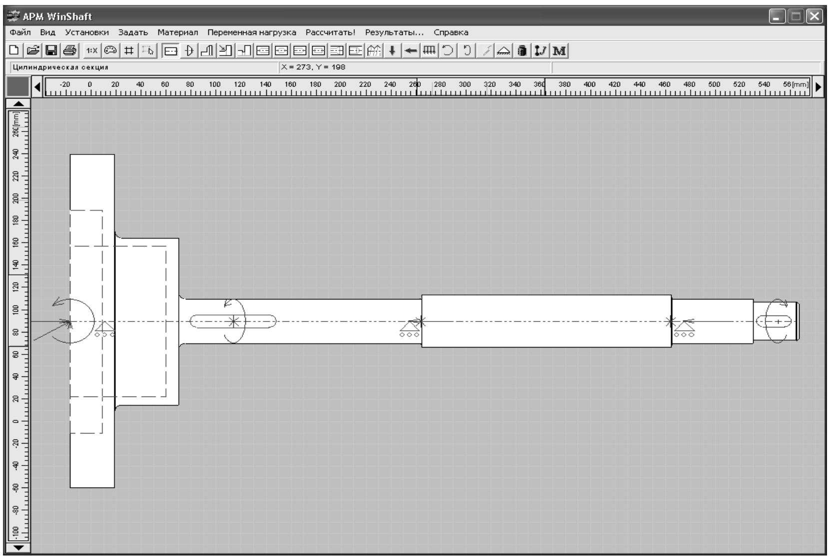

Fig. 4 Settlement scheme of statically indefinable leading shaft with wheel (option 3)

RESULTS AND DISCUSSION

As a result of performance of engine calculations for the considered versions of settlement schemes of the leading shaft values of reserve factor on fatigue strength of n_{fat}, equivalent normal tension σ_{eq} and conveyances of shaft of f as the provision of rated section of shaft are received. The maximum values of tension and reserve factor and also conveyance of the console end of shaft of f_{cons} are given in Tab. 1.

Tab. 1 Summary results of calculation of versions of settlement schemes of the leading shaft

Parameters	σ_{eq} , MPa	f_{cons} , mm	n_{fat}
Statically definable scheme of shaft (Fig. 2)	641	0.406	0.385
Statically indefinable scheme of shaft (Fig. 3)	149	0.000	0.804
Statically indefinable scheme of shaft with wheel (Fig. 4)	24.8	0.100	4.210

Analysis of data of Tab. 1 has allowed to draw the following partial conclusions (*Birger I.A. et al., 1993*): 1) equivalent normal tension for of statically definable shaft exceeds (option 1), and statically indefinable shaft (options 2 and 3) the allowed tension at bend for steel 40 (C40 EN) is σ_{adm}=200 (MPa) does not exceed; 2) practical check of conveyance of the console end of the leading shaft assembled with tooth gear at the stand by options 1 and 2 has shown offset of teeths of conical wheel in contact point on 5-10 (mm), in option 3 offset was absent; 3) for ensuring fatigue strength of shaft it is necessary to accept sufficient obtaining reserve factor of strength more than 3 that for options 1 and 2 is impracticable. Therefore, according to Tab. 1 of the compared versions 1, 2 and 3 of settlement schemes of the leading shaft (Fig. 2-4) at the stand it is necessary to apply introduction of the additional bearing parts of swing established to rim of gear conical wheels of reducer to realization i.e. by option 3. Graphic illustrations of calculated parameters are presented on Fig. 5-7.

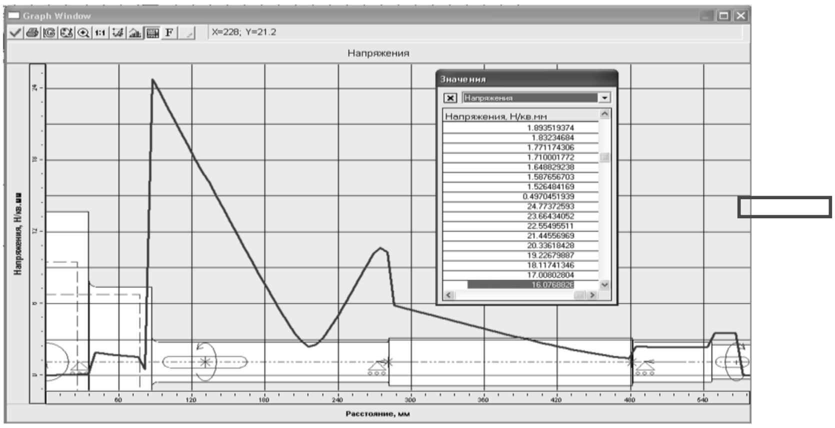

Fig. 5 Results of calculation of normal equivalent tension for shaft (option 3)

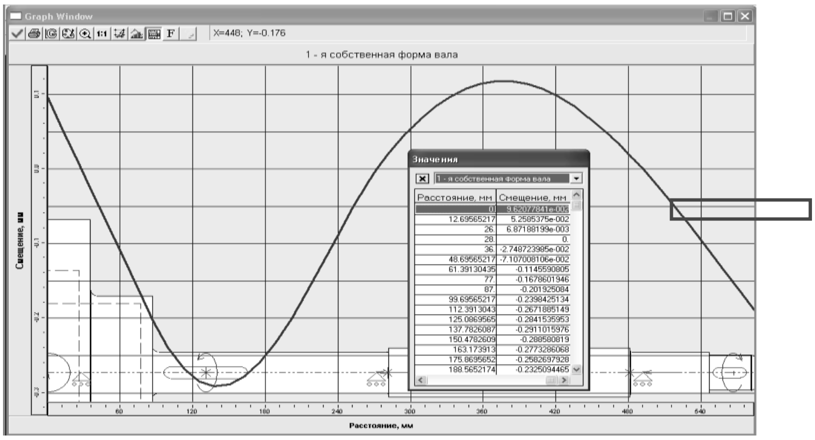

Fig. 6 Results of calculation of conveyances of the console end of shaft (option 3)

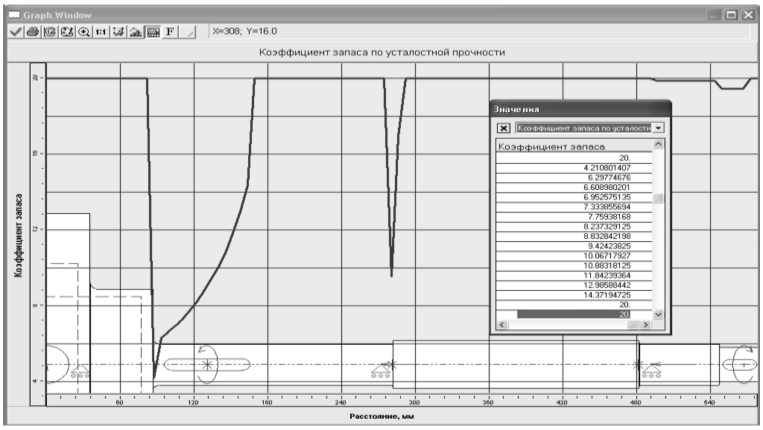

Fig. 7 Results of calculation of reserve factor of strength on fatigue for shaft (option 3)

As a result of production of intermediate bearing parts of swing and their installation in design of the test stand the technical tool for carrying out resource tests of cardan joints of unequal angular speeds is received. The general view of the stand with intermediate bearing part is presented on Fig. 8.

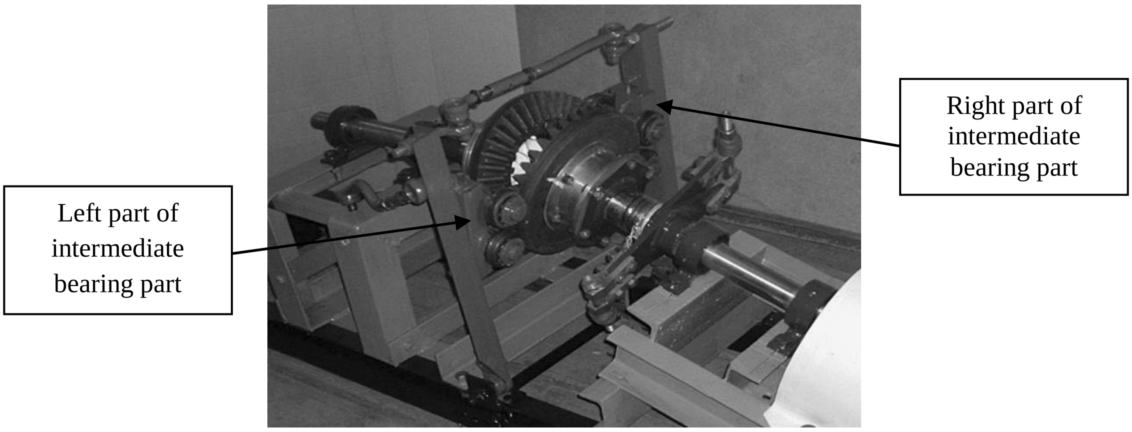

Fig. 8 General view of the stand for test of drive lines with intermediate bearing part

The subsequent technical evaluation of rationality of design has shown fidelity of the made decision on introduction of static indefinability at installation of shaft of the stand on the basis of CAE technologies as the loading of shaft has decreased, and the mass of the stand in comparison with analogs remained minimum (*Ašonja A., et al., 2013; Eresko S.P., 2016*). The metal construction of the stand allows to realize resource tests in the toughened mode. By comparison of results of development of this stand we note that similar technical solutions were applied also by other researchers for the purpose of ensuring durability and rigidity of the bearing shaft (*Ašonja A.N., 2014; Menovshchikov V.A., Eresko S.P., 2006*).

CONCLUSIONS

1. Ensuring durability and rigidity of power elements of the test stand allows to realize variability of the modes of loading of the experienced joints, gears and units of transmissions, both at the level of operation, and at the forced tests.
2. Introduction of static indefinability of design of shaft of the stand has led to ensuring high-quality contact piece of teeths of reducer that allows to realize as much as possible the potential of durability of technological drive of the stand at resource tests.
3. Use of CAE technologies when developing technical means for resource fail-safe tests is priority of development of production of the transport and technological equipment, owing to considerable drop of labor input and improvement of quality of process.

REFERENCES

1. Ašonja, A.N. (2014). The Influence of Diagnostic State of Reliability of Agriculture Double Cardan Shaft (in Serbian). *Scientific Journal Agricultural Engineering, 1*, 405-409.
2. Ašonja, A., Adamović, Ž., & Jevtić, N. (2013). Analysis of Reliability of Cardan Shafts Based on Condition Diagnostics of Bearing Assembly in Cardan Joints. *Journal Metalurgia International*, *18*(4), 216-221.
3. Birger, I.A., Shorr, B.F., & Iosilevich, G.B. (1993). *Calculation on durability of parts of machines* (in Russian). Reference book. Mechanical Engineering, 640 p.
4. Erokhin, M.N. & Pastukhov, A.G. (2008). *Reliability of drive lines of transmissions of agricultural machinery in operation* (in Russian). Monograph. Belgorod: BelSAA, 160 p.
5. Eresko, S.P., Eresko, T.T., Kukushkin, E.V., Menovshchikov, V.A., & Orlov, A.A. (2016). The design of the stand for testing cardan joints on needle bearings in a wide range of sizes with a change in the angle of fracture of the cardan drive (in Russian). *Transport. Transport facilities. Ecology,* 2, 58-73. doi: 10.15593/24111678/2016.02.05.
6. Flick, E.P. (1984). *Mechanical drives agricultural machines* (in Russian). Monograph. Moscow: Mechanical Engineering. 272 p.
7. Klyatis, L.M. & Khabatov, B.Sh. (1990). Features of the development and applications of test stands (in Russian). *Tractors and agricultural machines,* 5, 4-5.
8. Lamberson, L.R. & Kapur, K.S. (2009). *Reliability in engineering design*. Weliy India Pvt. Limited.
9. Menovshchikov, V.A. & Eresko, S.P. (2006). *Research and improvement of needle bearings of drive lines of transport and technological machines* (in Russian). Monograph. Krasnoyarsk State Agrarian University, 250 p.
10. Pastukhov, A.G. (2008). Advanced stands for resource tests of drive lines (in Russian). *Automotive industry, 5*, 35-37.
11. Pastukhov, A.G., Timashov, E.P., & Sharaya, O.A. (2018 *a*). Principles of designing and justification of parameters of the coaxial scheme of the power contour of the stand for resource tests of drive lines. In *Proceedings ISB-INMA TEH "Agricultural and mechanical engineering"* (pp. 101-106).
12. Pastukhov, A., Kolesnikov, A., Bakharev, D., & Berezhnaya, I. (2018 *b*). Assessment of operability of the crankshaft of the compressor. In *Engineering for Rural Development* (pp. 850-855). Jelgava, Latvia. doi: 10.22616/ERDev2018.17.N164.
13. Srivastava, A.K., Goering, C.E., Rohrbach, R.P., & Buckmaster, D.R. (2006). Engineering Principles of Agricultural Machines. *ASABE*.
14. Shelofast, V.V., Zamriy, A.A., Rozinsky, S.M., Shanin, D.V., & Alekhin, A.V. (2013). Practical training course. CAD/CAE APM WinMachine system (in Russian). *Teaching manual*, 144 p. Moscow: Publishing house APM.
15. Timashov, E.P. & Pastukhov, A.G. (2009). *Increase in durability of cardan joints of transport and technological machines in operation* (in Russian). Monograph. Stary Oskol: STI MISIS. 73 p.
16. Velichkin, I.N. (1999). Accelerated testing - the key to the competitiveness of technology (in Russian). *Tractors and agricultural machines,* No 3, 41-43.

Corresponding author:
Alexander Pastukhov, Dr. Sc. Ing., Professor, Hade of Department of Technical Mechanic and Machine Design, Faculty of Engineering, Belgorod State Agricultural University named after V.Gorin, Vavilov's street, 1, Maysky, Belgorod district, Belgorod region, 308503, Russian Federation, phone: +7-960 6276818, e-mail: pastukhov_ag@mail.ru