Procedure for determining the limit state parameters of John Deere tractor transmission units

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Abstract. Evaluation of reliability of transport and process machines in operation has considerable duration and low reliability. The purpose of the operation is to determine the parameters of the limit state of the transmission units, using the example of cardan joints. The estimated resource indicators are engine loading (based on data from the on-board computer), operating time (according to the on-board computer) and radial play (measured during observations) in the joint, using the example of the John Deere tractor. For laboratory studies, 12 cardan joints of the drive shafts of the gearbox hydraulic module were selected, decommissioned from six tractors upon reaching the maximum operating time established by the manufacturer. Tractors were operated in agricultural farms of the Belgorod region at various agricultural works: plowing, cultivation, disking, transportation. As a result of statistical processing, the average values of the limit state parameters of the tested cardan joints are established: 1) by load $N_{\text{mp}}=47.70\pm45.14$ kW; 2) by operating time $L_{\text{mp}}=6649\pm6441$ h; 3) along the radial play $\Delta_{\text{mp}}=0.274\pm0.201$ mm. The synthesis of the results made it possible to draw the following conclusions. First, specific values of the maximum state parameters of the unit are determined, which allow determining their operability. Second cardan joints with load within the limits of 47.70...92.84 kW have sufficient operability, but if necessary they increase durability and reliability and are suitable for carrying out maintenance actions. Third, cardan joints having operating time within 6649...13090 h and radial play 0.274...0.475 mm, if necessary, they are suitable for repair actions.

1. Introduction
The strategy of scientific and technical development of agriculture in Russia defines the main goal of creating the basis for innovative development of the domestic market of products and services, which will ensure the country's stable position in foreign markets. However, the level of technological and technical development of the domestic production base compared to the production base of the European Union, America and Canada is at a low level, which does not guarantee the necessary technical support of modern progressive technologies \cite{1}.

The main direction of increasing the competitiveness of transport and technological machines is the technological and technical modernization of the production base of the agro-industrial complex. In particular, the issues of technical service of machines and equipment are important in order to ensure its operability at a high level, not lower than foreign counterparts. There is a contradiction in this issue due to the lack of technical data on the limit states of units and assembly units of foreign equipment, which does not allow assessing its real reliability in operation based on diagnostics of the technical
The solution of the scientific problem of improving the quality of operated transport and technological machines in agriculture must be carried out, first of all, in hard operation, and especially after withdrawal from the guarantee. The importance of knowing the deadline before maintenance, repair or write-off is a very important aspect, since an assembly unit that has not been replaced on time leads to the failure of a more expensive unit, in particular for mechanical transmissions [3].

The task of this work is to quantify the main parameters of the limit state of assembly units based on the results of operational studies.

2. Materials and Methods
The object of the study is the cardan joint of the drive shaft of the John Deere tractor gear box. The main quantitative parameters of the technical condition assessment are operating time in hours (according to the data of the on-board computer), engine load (according to the on-board computer) and radial play (based on measurement using the installation). Operational information collection and experimental data processing are performed by RD 50-204-87 and ОСТ 70.2.8-82.

The research was carried out on 34 tractors operated at enterprises of the Belgorod region. During the processing of information, data on tractors with an operating time of less than 4500 hour were excluded due to minor wear of parts [4].

Installation, technological process and method of radial play measurement by means of upgraded dynamometer wrench and clock-type indicator for radial clearance measurement in tested cardan joint were developed. To carry out practical testing of the installation and the measurement method, radial play measurements were carried out in laboratory conditions, as well as for joints decommissioned from service due to excess of the maximum operating time established by the manufacturer [5]. The laboratory installation should be used to check and confirm the radial play value measured by the instrument, and the obtained radial play value at the installation allows one not only to clarify, but also reasonably to decide on the further operability of the unit. During the laboratory (in the repair shop) and operational (in the field) studies, two samples in the amount of 20 values were obtained. Operational measurements are carried out by the instrument directly in the field, and laboratory measurements are carried out by the installation in the conditions of the repair shop [6].

The method of processing truncated information on reliability indicators contains the following stages. The first is generation of results of analysis of radial play, operating time and load in the form of data tables; the second is the compilation of statistical series of initial information. The third is the determination of average value of reliability index and its mean square deviation; the fourth is check of information for drop-down points. The fifth is the construction of graphic image of experimental distribution of reliability indicators: histogram, polygon and curve of accumulated experimental probabilities; the sixth is the determination of the coefficient of variation. The seventh is the selection of the law of theoretical distribution for equalization of experimental information; the eighth is determination of confidence limits of dispersion of single and average reliability indices; the ninth is the determination of absolute and relative limit error of reliability indicator characteristics transfer [7].

3. Results and Discussion
In order to establish limit values of radial play and corresponding to parameter of loading and operating time data of tested cardan joints, empirical data on 12 failed units obtained in laboratory conditions were processed (Table 1).

As a result of the above procedure, the following quantitative values of limit parameters are obtained: 1) radial play - \( \Delta m \pm 3\sigma = 0,274 \pm 0,201 \) mm; 2) loading - \( N_m \pm 3\sigma = 47,7 \pm 45,14 \) kW; 3) operating time - \( L_m \pm 3\sigma = 6649 \pm 6441 \) h. Therefore, for further operational studies, radial play data within 0,274…0,475 mm, loading – 47,7…92,8 kW and operating time – 6649…13090 h are of interest.

We consider sequentially the processing of operational information according to the following parameters (Table 2).
### Table 1. Data of limit parameters for decommissioned cardan joints.

| No. of joints | Operating time L, h | Loading N, kW | Radial play Δ, mm |
|---------------|---------------------|---------------|-------------------|
| 1             | 4674                | 67.4          | 0.34              |
| 2             | 4674                | 67.4          | 0.39              |
| 3             | 4925                | 57.3          | 0.25              |
| 4             | 4925                | 57.3          | 0.25              |
| 5             | 5000                | 47.7          | 0.28              |
| 6             | 5000                | 47.7          | 0.29              |
| 7             | 8121                | 42.2          | 0.28              |
| 8             | 8121                | 42.2          | 0.31              |
| 9             | 10527               | 61.9          | 0.58              |
| 10            | 10527               | 61.9          | 1.04              |
| 11            | 14774               | 23.9          | 0.18              |
| 12            | 14774               | 23.9          | 0.17              |

### Table 2. Data of operational observations on parameters for cardan joints.

| No. of joints | Operating time L, h | Loading N, kW | Radial play Δ, mm |
|---------------|---------------------|---------------|-------------------|
| 1             | 7473.3              | 67.054        | 0.374             |
| 2             | 10163.0             | 62.336        | 0.001             |
| 3             | 5724.6              | 56.738        | 0.601             |
| 4             | 7558.8              | 54.628        | 0.623             |
| 5             | 7811.8              | 53.617        | 0.632             |
| 6             | 2192.0              | 66.119        | 0.232             |
| 7             | 3537.5              | 64.678        | 0.423             |
| 8             | 6784.4              | 46.356        | 0.257             |
| 9             | 1724.2              | 60.669        | 0.189             |
| 10            | 9.2                 | 21.411        | 0.026             |
| 11            | 10.1                | 19.409        | 0.025             |
| 12            | 3.6                 | 17.050        | 0.280             |
| 13            | 6.0                 | 16.189        | 0.023             |
| 14            | 11.0                | 18.191        | 0.031             |
| 15            | 5.0                 | 16.053        | 0.019             |
| 16            | 7.4                 | 17.144        | 0.017             |
| 17            | 3685.0              | 68.887        | 0.343             |
| 18            | 2414.5              | 48.939        | 0.291             |
| 19            | 10527.1             | 61.871        | 1.037             |
| 20            | 5700.8              | 57.505        | 0.695             |
| 21            | 5633.4              | 54.593        | 0.482             |
| 22            | 7488.9              | 44.309        | 0.377             |
| 23            | 4968.0              | 77.263        | 0.279             |
| 24            | 5067.2              | 47.680        | 0.396             |
| 25            | 745.1               | 61.578        | 0.089             |
| 26            | 532.0               | 64.578        | 0.060             |
| 27            | 7252.0              | 66.829        | 0.711             |
| 28            | 7900.0              | 42.829        | 0.250             |
| 29            | 8600.0              | 42.229        | 0.310             |
| 30            | 5744.3              | 65.511        | 0.730             |
| 31            | 1934.0              | 46.559        | 0.220             |
| 32            | 2219.0              | 49.429        | 0.283             |
| 33            | 14774.0             | 23.911        | 0.350             |
| 34            | 250.0               | 37.511        | 0.042             |
| 35            | 1227.0              | 67.893        | 0.428             |

The refined sample of the evaluation of the data on operating time is 25 elements and has the
following statistical characteristics: the average value \( L_m = 6661 \) h, standard deviation \( L_\sigma = 1697 \) h, the smallest value \( L_{\text{min}} = 1568 \) h, the greatest value \( L_{\text{max}} = 11753 \) h. Based on the obtained data of the operating time (Table 2), empirical (Figure 1, a) and theoretical (Figure 1, b) distributions of operating time are built.

![Empirical and Theoretical Distributions](image)

**Figure 1.** Empirical (a) and theoretical (b) distribution of operating time of tested cardan joints \( L, \) h.

The estimate of the sample by the coefficient of variation shows that \( \nu = 0.66, \) so the sample belongs to the Weibull distribution law, for which the parameters of the distribution law are \( a = 2858 \) and \( b = 1.55, \) as shown in the expression (1) of the Weibull production time distribution law:

\[
F(l) = \frac{1.55}{2858} \left( \frac{L}{2858} \right)^{0.55} e^{-\left( \frac{L}{2858} \right)^{1.55}}. \tag{1}
\]

Figure 1, a and b shows that the average operating time of the units without maintenance was 6661 hours. At the same time, 95% of cardan joints have an operating time of up to 6661 hours and only 5% of tractors with an operating time of more than 6661 hours.

The following data were finally obtained: confidence limits of scattering of single indicators with probability 0.9 upper 4346 h and lower 6804 h of deviation; confidence limits of scattering of average operating time value - lower 6316 h and upper 7105 h, relative transfer error - lower 5.2% and upper 6.7%.
The load sample is evaluated for 35 elements (Table 2) and has the following statistical characteristics: average value - $N_{\text{avg}}=49.7$ kW, standard deviation - $N_\sigma=18.6$ kW, lowest value - $N_{\text{min}}=16.1$ kW, highest value - $N_{\text{max}}=77.3$ kW. According to the obtained loading data (Table 2), empirical (Figure 2, a) and theoretical (Figure 2, b) loading distributions are built.

![Empirical and Theoretical Distributions](image)

**Figure 2.** Empirical (a) and theoretical (b) distribution of load of examined cardan joints $N$, kW.

The coefficient of variation in the sample is $\nu=0.50$, therefore, this sample belongs to the Weibull distribution law with the parameters of the law of distribution - $a=42.7$ and $b=2.15$, while the expression of the Weibull distribution law has the form:

$$F(N) = \frac{2.15}{42.69} \left(\frac{N}{42.69}\right)^{1.15} e^{-\left(\frac{N}{42.69}\right)^{1.15}}. \quad (2)$$

In the load data array (Figure 2, a and b), it is shown that the tested cardan joints are loaded at an average of 47.7 kW, the share of joints with a load not exceeding 47.7 kW is 73%, and with a load above 47.7 kW is 27%.

Finally, we get the load: the confidence scattering boundaries of single indicators with probability 0.9 are lower 15.6 kW and upper 52.3 kW, the confidence scattering boundaries of the average load value
are lower 46.0 kW and upper 54.3 kW, the relative transfer error is lower 7.5 % and upper 9.3 %.

The refined radial play sample, after checking for drop-out points, was 28 elements (Table 2) and has the following statistical characteristics: average value $\Delta_m=0.370$ mm, standard deviation $\Delta_\sigma=0.118$ mm, smallest value $\Delta_{\text{min}}=0.110$ mm, largest value $\Delta_{\text{max}}=0.720$ mm. Based on the obtained data of the radial play (Table 3), empirical (Figure 3, a) and theoretical (Figure 3, b) distributions of the radial play are built.

The coefficient of variation of the radial play sample is $\nu=0.71$, which indicates that the sample belongs to the Weibull distribution law with the parameters of the distribution law - $a=0.1846$ and $b=1.425$, then the expression of the Weibull distribution law has the form:

$$F(\Delta) = \frac{1.425}{0.1846} \left( \frac{\Delta}{0.1846} \right)^{0.425} e^{-\left( \frac{\Delta}{0.1846} \right)^{1.425}}. \quad (3)$$

Based on the analysis of information in Figure 3, a and b, we obtain that for the average limit radial play of $\Delta=0.274$ mm, the proportion of cardan joints for which maintenance is possible is 85 %, and the rest (15 %) are subject to repair and restoration work.

Thus, as a result of data processing, we obtain: confidence scattering boundaries of single indicators with probability 0.9 for lower 0.200 mm and upper 0.400 mm boundaries, confidence scattering boundaries of the average value of the play along the lower limit 0.300 mm and the upper...
limit 0.400 mm, the relative transfer error is lower 6.6 % and upper 8.7 %.

The synthesis and comparison of the above results with the studies carried out earlier show that the methodology for determining the limit state parameters for various units and assemblies of foreign tractors makes it possible to determine clearly the maintenance periodicity and maintenance costs [8,9,10].

4. Conclusion

Based on the statistical analysis of the results of laboratory studies of decommissioned cardan joints as a result of the failure, the parameters of the limit state were established: radial play - $\Delta_m=0.274$ mm, loading - $N_m=47.7$ kW, operating time - $L_m=6661$ h. At that, cardan joints with a radial play of more than 0.274 mm with a loading of more than 47.7 kW at the operating time of not less than 6649 h are subject to testing.

Analysis of research data on the parameters of the limit state of cardan joints for tractors John Deere series 7 showed: 95% of joints have an operating time of up to 6661 hours and only 5 % with an operating time of more than 6661 hours; the share of joints with a load not exceeding 47.7 kW for the engine is 73 %, and the share with a load above 47.7 kW is 27 %; with an average radial play of $\Delta_m=0.274$ mm for 85 % of the units in operation, maintenance measures are applicable, and the remaining 15 % are subject to replacement or repair.

In the future, for the combinations of load, operating time and radial play observed in operation, for example, for cardan joints, a significant increase in durability and reliability is possible due to the use of original maintenance methods. Therefore, the establishment of limit state parameters is a real factor in reducing the labor intensity and costs of technical service of transport and technological machines.

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