Influence of imbalance of balancing of crankshafts during engine repair

G Kokieva1,3,6, N Moshkin2, V Druznova3, D Radnayev4, and N Khiterkheyeva5

1 Arctic State Agrotechnological University, Sergelyakhskoe highway, 3 km, building 3, 677007, Yakutsk, Republic of Sakha (Yakutia), Russia
2 Buryat State Agricultural Academy named after V.R. Filippova, Pushkin str., 8, 670034, Ulan-Ude, Republic of Buryatia, Russia
3 North-Eastern Federal University named after M.K. Ammosov, Belinsky st., 58, 677007, Yakutsk, Republic of Sakha (Yakutia), Russia
4 Buryat State Agricultural Academy named after V.R. Filippova, Pushkin str., 8, 670034, Ulan-Ude, Republic of Buryatia, Russia
5 Buryat State University named after Dorzhi Banzarov, Smolina str., 24a, 670000, Ulan-Ude, Republic of Buryatia, Russia

E-mail: kokievagalia@mail.ru

Abstract. Currently, tractors and other complex machines repaired at advanced repair enterprises perform worse than new ones and have a shorter overhaul life. Let us consider what losses in the quality of the car are not replenished even with a well-organized repair in compliance with the existing technical conditions and whether they are really recoverable. If during the repair the car was assembled entirely from new good-quality parts and the required technical conditions were observed during the assembly, then no loss of serviceability of the machine during repair could take place. This means that it is difficult to eliminate the losses associated with the use during repair, firstly, partially worn out (with acceptable wear and tear) and, secondly, restored parts. The experience of using agricultural machinery shows that by using maintenance and repair tools that do not require large investments, it is possible to significantly reduce the downtime of the machine and tractor fleet. With the introduction of new, more progressive technological processes into technology, an increase in the speed and power of technology, as well as with the tasks of automatic regulation and control of machines, machine designs have radically changed. Along with the mechanical ones, the machines include hydraulic, pneumatic, electrical, electronic devices. The imbalance in the correction planes of the crankshafts assembled with a flywheel and clutch supplied to spare parts is 1.2-6.5 times and 1.3-10.7 times, respectively, higher than the allowable one. After grinding the main and connecting rod journals for repair dimensions, the imbalance of these assembly units is also 1.5-7.2 and 1.7-12.3 times greater than the permissible unbalance of the crankshafts and to develop recommendations for improving the balancing accuracy during engine repair.

1. Introduction
The problems of durability and reliability of machines are of interest not only to scientists, designers and machine builders. To an even greater extent they occupy consumers who operate machines, organize their maintenance and repair. The total imbalance in the correction planes of automotive
engines is an indicator of the quality of manufacture and repair. This is explained by the fact that, unlike old low-speed machines with a large margin of safety, modern machines use structural (parts) and non-structural (assembly, adjustment, painting, lubrication, etc.) elements designed for different durations and periodically requiring replacement or renewal. It is determined by design, technological, operational and repair factors and is reduced to the planes of the flywheel and crankshaft pulley. The imbalance affects the engine life and vibroacoustic indicators, wear rate and uneven wear of the crankshaft bearings. Therefore, the permissible value must be technically and economically justified, achievable in terms of production and repair. The permissible engine imbalance is the largest residual in the considered plane, perpendicular to the crankshaft axis, which is considered acceptable. The main quality indicators of engines (vibration, noise, resource, speed and uneven wear of the main journals, an increase in the clearance and its unevenness in the main bearings of the crankshaft) depend on the value and angle of unbalance in these planes. Therefore, the permissible imbalance in the correction planes is such that the quality indicators of the engine have practically the same values as with the attainable initial unbalance at any values of the angle between its vectors in the said planes. When determining the permissible imbalance, it should be borne in mind that its decrease below a certain value does not affect the quality indicators, but sharply increases the cost of manufacturing and repair. In the case of an increase in imbalance, a sharp deterioration in vibroacoustic performance and reliability occurs. The permissible imbalance of the engine is supposed to be determined based on its vibrational displacement and vibration in the transverse direction.

2. Research methodology

The peculiarity of agricultural production - climatic conditions, the effects of atmospheric factors, dustiness, contact with biological objects - significantly complicate the operation of equipment, reduce the durability of components and assemblies. Its reliability is determined by four main properties: reliability, durability, maintainability and preservation. All of them are laid down and supported at the design, production, operation and repair stages. However, the engineering service can radically affect the reliability only during operation and during repair and restoration work. The causes of failures are fatigue, corrosion and wear. One of the main reasons for the failure of the crankshafts of tractor diesel engines is a significant deflection of the main journals. In the absence of this defect and relatively uniform wear of the main and connecting rod journals, they are ground to the same repair size (23 ... 25% of the shafts). In case of uneven wear, the presence of annular notches, journal jamming, it is
necessary to grind after one, two or even three repair sizes, and in the latter case, the resource of the shafts decreases by 20 ... 30%, the processing time increases significantly.

The crankshaft is one of the most loaded parts, which determines its resource as a whole. Its main defects are wear and fatigue destruction of the main and connecting rod journals. The main types of working parts and assemblies of modern agricultural machines can give a good quality of work at a speed of 7-9 km/h, and in some cases up to 11-12 km/h. At the same time, tractor units should not have too large a grip [1,7,12]. aggregates with a large grip are dynamically unstable, do not adapt well to the terrain and give a low quality of work. on fields bounded by natural obstacles they are low-maneuverable, spend a lot of time on idle runs, leave the corner sections of the fields poorly cultivated, their passability on roads and bridges is low.

The operational reliability of units with many machines is low, which reduces their productivity. Tractors for such units, if necessary, must be heavy and slow-moving, they are suitable in agriculture only for special conditions. Oscillations and vibrations, internal and external noises of agricultural and transport vehicles are mainly caused by vibroacoustic indicators of engines. one of the main sources of vibration and mechanical noise in motors is imbalance in the correction planes. it also affects the resource, the degree of wear of the main bearings of the crankshaft and is an indicator of the quality of design, production, operation and repair, determined by deviations of mass and geometric parameters, residual unbalance and eccentricity of parts, installation and current clearances in joints, various operational and repair factors.

Modern technology is characterized by further intensification of the operating modes of machines, which leads to a significant increase in loads on the working surface of parts, assemblies and, especially, movable interfaces (friction units). The main reason for failures in the operation of machines is not their breakdown, but the wear of the working surfaces, which makes the problem of reliability and increase the resource of parts urgent [5, 11, 13]. In connection with the depletion of natural mineral resources, the problem of processing and further use of automotive waste, as well as the restoration of worn-out parts is becoming more and more urgent [2-4]. The technical condition of the diesel engine crankshaft speed control can be more accurately estimated by the ratio [6,9]:

\[ \delta_p = \frac{H_p}{H_{pu}} , \]  

(1)

where \( \delta_p \) – relative unevenness of the regulator; \( H_p, H_{pu} \) – respectively, the actual and nominal values of the unevenness of the regulator, which are the increment in the rotational speed per unit of cycle fuel supply.

\[ H_p = (n_1 - n_2)/(q_{u2} - q_{u1}) , \]  

(2)

where \( n_1, q_{u1} \) – respectively, the speed of the camshaft of the fuel pump and the cyclic fuel supply at reduced load; \( n_2 \) and \( q_{u2} \) – the same with increased load.

In a geometric interpretation, unevenness \( H_p \) the operation of the regulator is characterized by the slope of the curve \( n = f(q_u) \). Value \( H_p \) can be measured both directly on a diesel engine and on a non-motorized stand. For the same fuel pump, the value \( H_p \) in both cases will be the same.

By value \( H_p \) evaluate the design features of the new regulator complete with a reference pump, а по значению \( \delta_p \) – technical condition of a worn-out regulator.

To confirm the benefits of the parameter \( \delta_p \) we give a formula for the relationship of the relative unevenness of the regulator operation with the wear of its parts:

\[ \delta_p = K(\sqrt{H_1 + C_M}(R_1 + \Delta R) - \sqrt{(H_2 + C_M)(R_2 + \Delta R)} / \sqrt{H_2 / R_2} , \]  

(3)

where \( K = \sqrt{B/\Delta R} \) – coefficient taking into account the change in the stiffness of the regulator spring; \( B, \Delta R \) – respectively, the actual and nominal spring rate, kg/mm; \( H \) – regulator spring tension, mm; \( C_M \) – total clearance in regulator mates, mm; \( R \) – distance from the center of gravity of weights to
the axis of the regulator roller, mm; $\Delta R$ – clearance at mating of cargo axes, mm; indexes 1 and 2 – diesel engine load modes.

The parameters included in formula (2) relate only to the state of the regulator. As a result of the wear of the axles and bushings of the weights, the holes in the cross-piece, the turning radius of the weights, and, consequently, the distance from their center of gravity to the axis of the regulator roller increases. As can be seen from formula (2), this leads to a decrease in $\delta_p$.

As the operating time, the total wear $C_p$ parts of the regulator increases, and the rigidity $R$ of the spring decreases. Wherein in the first case $\delta_p$ increases, in the second it decreases. Consequently, the increase in wear of the regulator parts is compensated for by a decrease in the spring rate. Therefore, when determining the technical condition of the regulator due to wear of the above mates, the spring stiffness should be checked and restored to the nominal value [10, 15]. Then again determine $\delta_p$ and the obtained result is used to estimate the wear of the regulator mates.

With an excessive decrease $\delta_p$, self-oscillations of the automatic control system occur, accompanied by an unstable movement of the machine-tractor unit (MTA), and with an excessive increase in $\delta_p$, the unevenness of the crankshaft rotation increases. In both cases, the service life and reliability of the MTA are reduced.

3. Research results and discussion

One of the main parameters characterizing the performance of the regulator is unevenness $Y_\delta$ work by which it is possible to assess its technical condition, due to wear of the interfaces. Table 1 lists the factors that affect the position of the governor sleeve.

The degree of unevenness is taken as private functions $Y_\delta$ regulator and relative unevenness $Y_{\delta p}$ its work. The following standard values of these quantities are established: $Y_\delta \max = 11.6$%; $Y_\delta \min = 3.7$%, nominal (with a rating ”good”) $Y_{\delta p}^{\text{exp}} = 7$% [4]; $Y_{\delta p} \max = 2.1$; $Y_{\delta p} \min = 0.5$; $Y_{\delta p}^{\text{exp}} = 1.0$ [8, 14].

Various methods of straightening are known: cold straightening - on presses by repeated bending; hot - most often on screw presses; thermal - by heating the middle connecting rod journals using high frequency current (HFC) and water cooling from the concave side; press identifier; selective knurling of fillets; chasing fillets and cheeks.

| Table 1. Factors affecting regulator clutch position |
|-----------------------------------------------|
| Factor | Measurement levels |
| Wear, mm: | | |
| Load axles – $X_1$ | 0.00 | 0.25 | 0.42 | 0.59 | 0.79 |
| Lever axles – $X_2$ | 0.00 | 0.25 | 0.42 | 0.59 | 0.79 |
| Couplings – $X_3$ | 0.00 | 0.45 | 0.82 | 1.22 | 1.70 |
| Roller axles $X_4$ | 0.00 | 0.25 | 0.45 | 0.65 | 0.89 |
| Spring rate $X_5$, kg/mm | 0.22 | 0.22 | 0.21 | 0.20 | 0.19 |

The main characteristics of the regression equations with the most significant terms that have a significant impact on $D_1$, ($Y_\delta$) and $D_2$, ($Y_{\delta p}$), are presented in the table 2.

| Table 2. The main characteristics of the regression equation that have the greatest impact on $D_1$, ($Y_\delta$) |
|-----------------------------------------------|
| Name of characteristics | Factors |
| $X_1, X_3, X_4, X_5$ | $X_3, X_5$ | $X_1, X_3, X_5$ |
| Coefficients $b$ of the equation | 3.0272 | -0.7256 | 1.1310 |
| t- Student's ratios | 3.4281 | -2.4219 | 2.1986 |
the equation:
\[ R = 0.5840 \] – Adjusted multiple correlation coefficient
\[ D1 = 0.3411 \] – Multiple determination coefficient
\[ b_0 = 0.5374 \] – Free term of the equation

As a result of shafts being straightened on presses by bending, their fatigue strength decreases by an average of 10–15% (maximum by 30%). Therefore, this editing method is not always recommended. In some cases only, it is acceptable after preliminary hardening by knurling fillets. Index straightening on presses is efficient and not laborious for three or four loads (Figure 1) to eliminate significant deflection.

![Figure 1](image-url)

**Figure 1.** Dependence of the tension of the shafts on the deflection for various methods of straightening: 1 – diesel engines A=41, straightened on the press; 2 – diesel engines D=240 after simultaneous rolling of fillets and straightening on the press; 3 – diesel engines YMZ=238NB, straightened by chasing fillets; 4 – engines ZMZ=53; straightened by the indicator on the press.

As can be seen from Fig. 1, the stress of the shafts increases with an increase in their deformation: maximum - in jammed ones; less - for shafts received for repair, including those with separate journals; even smaller - for shafts hardened using HFC; minimum - for shafts with rolled fillets. Technological documentation for the repair of tractor diesel engines and their parts usually does not specify the amount of shaft deflection allowed for straightening.

4. Conclusions
Each machine in operation is repaired many times and a large amount of labor and spare parts is spent on maintaining it in working condition for 6-8 years, and these costs increase over time. This is largely due to the insufficient reliability and durability of tractors and agricultural machines, the unevenness of their elements, and the instability of adjustments. As practice shows, small-sized crankshafts are cheaper to replace with new ones, and large-sized crankshafts are more economical to restore. In this case, the restoration allows you to get significant savings in material, production and labor resources. In this regard, improving the technological quality assurance of the crankshaft restoration on the basis
of a comprehensive study of the basic metal coating operation, which serves to form a secondary blank of the restored part, and further machining was an urgent task. Oscillations and vibrations, internal and external noise of agricultural and transport vehicles are mainly caused by vibroacoustic indicators of engines.

One of the main sources of vibration and mechanical noise in motors is imbalance in the correction planes. It also affects the resource, the degree of wear of the main bearings of the crankshaft and is an indicator of the quality of design, production, operation and repair, is determined by deviations of mass and geometric parameters, residual unbalance and eccentricity of parts, installation and current clearances in joints, various operational and repair factors. The end result of various studies on machine wear is to determine the patterns of wear growth and establish their service life. Thus, the wear of the main mates and the stiffness of the spring of the speed regulator have a significant effect on the unevenness of its operation, which can be taken as one of the diagnostic parameters characterizing the operability of the automatic control system.

References
[1] Kravchenko V, Kravchenko L and Oberemok V 2020 E3S Web of Conferences 175, 05017 INTERAGROMASH 2020 https://doi.org/10.1051/e3sconf/202017505017
[2] Chayka Y, Zhurba V, Krivtsova N, Khadzhidi A, Voshchevoz P and Natia Ugrekhelidze 2020 E3S Web of Conferences 175, 09007 INTERAGROMASH 2020 https://doi.org/10.1051/e3sconf/202017509007
[3] Kambulov S I, Bozhko I V and Olshesvkaya AV 2018 MATEC Web of Conferences 224, 05022 https://doi.org/10.1051/matecconf/201822405022
[4] Ivanov Yu. A., Pakhomov V I, Kambulov S I, Rudoi D V 2018 (ICMTMTE 2018) electronic edition. Cep. MATEC Web of Conferences 224, 05023 https://doi.org/10.1051/matecconf/201822405023
[5] Ivanov V V, Popov S I, Dontsov N S and Kotesova A A 2020 The oxide film formation under vibration processing in the high-resource parts manufacture in transport engineering International Scientific Conference «Construction and Architecture: Theory and Practice for the innovation Development» (CATPID-2020): IOP Conference Series: Materials Science and Engineering, 913, pp. 042056 doi:10.1088/1757-899X/913/4/042056
[6] Bozhko I, Parkhomenko G, Kambulov S, Boyko A, Kolodkin V, Magomedov M and Rudoy D 2020 E3S Web of Conferences 175, 05025 INTERAGROMASH 2020 https://doi.org/10.1051/e3sconf/202017505025
[7] Lachuga Y, Soloviev A, Matrosov A, Panfilov I, Pakhomov V and Rudoy D 2019 IOP Conf. Series: Earth and Environmental Science 403 012055 IOP Publishing doi:10.1088/1755-1315/403/1/012055
[8] Shvetsov A V, Daramaeva A, Kokieva G E, Kozyrev V A and Odudenko T A 2019 Methodology for assessing the risk of an act unlawful interference on transport systems. IOP Conference Series: Materials Science and Engineering, The International Scientific Conference “Construction and Architecture: Theory and Practice for the innovation Development” (CATPID-2019) p. 066067
[9] Kokieva G E, Voinash S A, Sokolova V A, Fedyayev A A, Fedyayev A A 2020 The study of soil mechanics and intensification of agriculture IOP Conference Series: Earth and Environmental Science 548(6), 062036
[10] Zavalii A, Volozhaninov S, Shiian O, Rudoy D and Olshesvkaya A 2020 E3S Web of Conferences 175, 05003 INTERAGROMASH 2020 https://doi.org/10.1051/e3sconf/202017505003
[11] Parkhomenko G, Bozhko I, Kambulov S, Boyko A, Polushkin O, Lebeden V, Beskopilniy A and Olshesvkaya A 2020 E3S Web of Conferences 175, 09006 INTERAGROMASH 2020 https://doi.org/10.1051/e3sconf/202017509006
[12] Nesmiyan A, Kravchenko L, Khizhnyak V and Zubrilina E 2020 E3S Web of Conferences 175, 05019 INTERAGROMASH 2020

[13] Meskhi B, Golev B, Efros V, Rudoy D, Olshevskaya A, Zhurba V and Chayka Y 2019 E3S Web of Conferences 135, 01083 ITESE-2019 https://doi.org/10.1051/e3sconf/201913501083

[14] Rudov S, Shapiro V, Grigorev I, Bondarenko A and Radnaed D 2019 Specific features of influence of propulsion plants of the wheel-tyre tractors upon the cryomorphic soils, soils, and soil grounds International Journal of Civil Engineering and Technology 10(1), pp. 2052-2071

[15] Shaposhnikov Y A, Druyanova V P, Kokieva G E, Nifontov K R and Sidorov M N 2018 The increasing of work efficiency of mixing machines PeriodicoTcheQuimica 15(1), pp. 67-76