Design of the gauge plug for inspection of the diameters of bushing bores of the intermediary shaft for the repairs of engines for agricultural machinery

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Abstract. This article contains substantiation of the improvement of inspection instruments used for the repairs of farming machinery during incoming quality inspection, in-process inspection, and acceptance testing. The design of a gauge plug has been developed for repairs and with the purpose of inspection of bushing bores of the intermediary shaft bearing with the diameter of Ø48.8F7 for ZMZ engines. The manufacturing tolerance for go-side and no-go side has been determined. The deviation of the middle of the tolerance range in relation to the smallest limiting size of the gauge plug was 3.5 µm. The permissible overrun of a worn-out of the go-gauge outside of the tolerance range border was – 3 µm. The manufacturing tolerance for the size of the check caliper gauge has also been determined and limiting dimensions of the check gauge have been calculated. Taking into account the values derived a layout for the gauge plug tolerance range has been developed in order to inspect the bushing bores of the intermediary shaft bearing with the diameter of Ø48,8+0,050+0,025.

1. Introduction
In the Russian agroindustrial complex they use lots of speciality and multipurpose machinery: combine harvesters, tractors, heavy-duty vehicles, attachments, trailing equipment, etc. All this machinery requires maintenance and repairs, both current and capital repairs. Farming machinery repairs is a rather difficult and labor-intensive process [1,2], in which measurement inspection plays a vital role. In the process of operation most joint assemblies of farming machinery is subject to wear, gaps and clearances increase [3,4], interferences change [5,6], and a complex process of degradation takes place in seal assemblies [7,8]. Higher degree of precision is required as it forms the wear margin, and in order to reduce allowances during assembly the incomplete interchangeability methods are applied [9,10]. Failures take place in case of long-term operation, and farming machinery requires repairs. Incoming quality inspection is the most important operation in the repairs process. During this type of inspection parts and components of machinery and equipment are sorted by groups: Those suitable for further operation, those requiring repairs, and rejected ones [11]. QC department and legal metrology department of an enterprise are responsible for the selection of instruments and methods of incoming quality inspection, in-process inspection, and acceptance testing [12,13]. Enhanced precision of new and repaired parts, as required by modern-day machinery production, dictates the need for using new measurement tools allowing for increased cost of inspection [14] and, most importantly, it stipulates for...
the substantiation of the probability of occurrence of losses due to inaccuracy of measuring instruments [15, 16].

Gazel and Sobol are the vehicles that have been in high demand in the Russian agroindustrial complex. Both are light duty commercial and passenger vehicles manufactured by GAZ concern. These vehicles are widely used by both large agroindustrial holding companies and small farms. In the course of their operation assemblies and devices of these vehicles get worn out. The intermediary or transmission shaft is one of the connecting shafts that limit the vehicle engine’s service life. This shaft drives the oil pump and the camshafts. Joint bearings are used there; and their reliability directly depends on the quality of engine oils used. People driving these vehicles tend to use such engine oils sparingly to save costs. Mineral and semisynthetic oils are most often used with these engines. And since oil change deadlines are rarely met the joint bearings used are subjected to early-life failures. The intermediary shaft of ZMZ engine – 40524.10 is a weak point in the structure [17].

We propose to design and develop for ZMZ engine repair providers a gauge plug that inspects the quality of reworking this size of the front bearing journal of the intermediary shaft.

2. Findings and analysis

The intermediary shaft of ZMZ engine – 40524.10 is rotated inside two bushing in the form of bush bearings. In order to rework and restore the shaft it is designed to use the oversize of joint Ø48.8F7/f7. Bushings for repairs with the diameter of Ø48.8F7 are manufactured by the manufacturing facility. When repairing ZMZ engines the shaft is polished to the specified repairs dimensions, however, it is necessary to ensure not only the inspection quality for the shaft but for the bushings in order to produce acceptable quality joints.

Design of the gauge plug for inspection of bushing bores of the intermediary shaft bearing with the diameter of Ø48.8F7 must begin with the determination of characteristics of precision standards of the dimension inspected. As per GOST 25347 – 82 [18] we find the upper and lower limiting deviations, and the calculated values are shown in table 1.

| Intermediary shaft parameter | Reference designation | Value                  |
|------------------------------|-----------------------|------------------------|
| Upper deviation              | ES                    | + 50 мкм = + 0.050 мм   |
| Lower deviation              | EI                    | + 25 мкм = + 0.025 мм   |
| Maximum limiting dimension   | \( D_{\text{max}} = Dn + ES \) | 48.8 + 0.050 = 48.850 мм |
| Minimum limiting dimension   | \( D_{\text{min}} = Dn + EI \) | 48.8 + 0.025 = 48.825 мм |

For the tolerance grade \( IT7 \) and the range of sizes 30 mm…50 mm we find the data for calculation of the gauge sizes [18]:

\[
Z = 3.5 \, \mu m = 0.0035 \, mm; \quad \alpha = 0; \quad Y = 3 \, \mu m = 0.003 \, mm; \quad H = 4 \, \mu m = 0.004 \, mm; \quad Hp = 1.5 \, \mu m = 0.0015 \, mm;
\]

where \( Z \) – deviation of the middle of the tolerance range relative to the minimum limiting dimension;
\( Y \) – Permissible overrun of the go-gauge outside the tolerance range;
\( H \) – Manufacturing tolerance for the working gauge-bore;
\( Hp \) – Manufacturing tolerance for the check caliper gauge.

Formulas and results of intermediate calculations of the executive and limiting dimensions of the snap-gauge have presented in table 2.

| Gauge | Dimensions | Deviations |
|-------|------------|------------|
|       | Formula | Calculation results, mm | Formula | Calculation results, mm |
|       |         | |         | |
Go-side of the new gauge plug  
\[ D_{\text{min}+Z} = 48.825 + 0.0035 = \pm H/2 \pm 0.002 \]

Go-side of the run-out gauge plug  
\[ D_{\text{min} - Y + \alpha} = 48.825 - 0.003 + 0 = - \]

No-go-side of the gauge plug  
\[ D_{\text{max} - \alpha} = 48.850 - 0 = 48.850 \pm H/2 \pm 0.002 \]

Go-side of the check caliper gauge  
\[ D_{\text{min}+Z} = 48.825 + 0.0035 = \pm H_p/2 \pm 0.00075 \]

No-go-side of the check caliper gauge  
\[ D_{\text{max} - \alpha} = 48.850 - 0 = 48.850 \pm H_p/2 \pm 0.00075 \]

Design parameters of the limiting dimensions of the gauge plug designed for inspection of bushing bores of the intermediary shaft bearing for ZMZ-406 are shown in table 3.

| Gauge plug parameter | Reference designation | Calculated value, mm |
|----------------------|-----------------------|----------------------|
| Maximum dimension of the go-side | Go_{max} | 48.8305 |
| Minimum dimension of the go-side | Go_{min} | 48.8265 |
| Maximum dimension of the no-go-side | No-Go_{max} | 48.8520 |
| Minimum dimension of the no-go-side | No-Go_{min} | 48.8480 |
| Limiting dimension of the run-out side | Go_{\text{worn}} | 48.8220 |
| Required dimensions of the go-side | Go_{ex} = Go_{\text{min}} + H | 48.8305 \pm 0.004 |
| Required dimensions of the no-go-side | No-Go_{ex} = No-Go_{\text{min}} + H | 48.8520 \pm 0.004 |

In order to inspect dimensions of the gauge plug designed it is necessary to calculate limiting dimensions of the check gauge. The formulas and calculated values of limiting dimensions of the check gauge are shown in table 4.

| Gauge plug parameter | Reference designation | Calculated value, mm |
|----------------------|-----------------------|----------------------|
| Maximum limiting dimension of the check go-caliper gauge | D_{\text{min}+Z} + H_p/2 | 48.8300 |
| Minimum limiting dimension of the check go-caliper gauge | D_{\text{min}+Z} - H_p/2 | 48.8270 |
| Maximum limiting dimension of the check no-go-caliper gauge | D_{\text{max} + H_p /2} | 48.8515 |
| Minimum limiting dimension of the check no-go-caliper gauge | D_{\text{max} - H_p /2} | 48.8485 |
| Maximum limiting dimension of the check caliper gauge for run-out inspection | D_{\text{min} - Y + \alpha + H_p /2} | 47.8235 |
| Minimum limiting dimension of the check caliper gauge for run-out inspection | D_{\text{min} - Y + \alpha - H_p /2} | 47.8205 |

The layout for the gauge plug tolerance range has been developed in order to inspect the bushing bores of the intermediary shaft bearing with the diameter of Ø48.8F7, which was developed based on the calculations, is shown in shown in figure 1.
3. Conclusions

Thus, the gauge plug has been designed and developed for the repairs and with the purpose of inspection of bushing bores of the intermediary shaft bearing for ZMZ engine – 40524.10 in case of repairs featuring replacement of run-out bushing with oversize bushings with the purpose of ensuing their mounting into the assembly Ø48.8F7/f7.

To ensure a smooth gauge plug is used in order to inspect the diameter of bushing bores of the intermediary shaft bearings of ZMZ engine – 40524.10 the following items have been defined:

- Boundary of the maximum permissible run-out.
- Manufacturing tolerance for the working gauge plug.
- Manufacturing tolerance for the check caliper gauge.
- Maximum size and minimum size of a go-side of the gauge plug.
- Maximum size and minimum size of a no-go-side of the gauge plug.
- Limiting size of the worn-out side of the gauge plug.
- Required dimensions of the gauge plug.
- Limiting dimensions of the check go-gauge plug.
- Limiting dimensions of the check gauge for runout inspection.
- Limiting dimensions of the check no-go gauge.

A layout for the gauge plug tolerance range has been developed in order to inspect the bushing bores of the intermediary shaft bearing with the diameter of Ø48.8F7.

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