Studying Surge Phenomena by Improving the Construction of a Turbocharger Testing Bench

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Abstract. It is common knowledge that diesel engines are frequently used in agricultural processes. Uprating a diesel engine by means of turbocharging is widely used nowadays. Turbocharging easily enables the increase in the power of the engine by 10-50%. However, the turbine creating a high effectiveness of a diesel engine became an essential problem connected with the reduction of reliability of farming machinery. One of the vital issues here refers to surge phenomena in a turbocharger. Thus, in routine maintenance of turbocharged engines the stochasticity of load leads to the changes in the geometry of the pump and turbine wheels of a turbocharger. The complex work to improve the construction of the turbocharger test bench was connected with re-creating the real operational modes of a turbocharger (TCR) on the bench and studying the limits of a surge during tests.

1. Introduction
The turbocharger in agricultural machinery helps not only uprate engines, increase their specific power but also ensure a complex improvement of indicators of their technical level such as fuel efficiency, environmental quality and reliability. However, when using a turbocharger there occur additional dynamic and temperature loads which can considerably reduce reliability [1]. One of the most difficult ones are dynamic loads caused by surge phenomena. A turbocharger surge is a failure in a turbine which is accompanied by pressure pulsation at the outlet and results in the shock loads of the impeller blade which can bring considerable damage in the short period of time. Presently machine builders considerably reduce the distance between the consumption of an engine and surge limits. These conditions are sure to bring such operational mode when a turbocharger, due to the supply of extraneous air into an engine, will work in the surge area. As a result, the diffuser part stops functioning normally and, when the critical value of pressure and consumption is reached, the air escapes from the turbine wheel wings producing the above-mentioned shock load on the impeller blade like a clap [2].

The stochasticity of loads on tractor engines leads to the increase in the fault dynamics [3]. Thus, in a routine maintenance operation of turbocharged engines the stochasticity of loads leads to the changes in the geometry of the pump and turbine wheels of a turbocharger and, as practice shows, it causes the...
destruction of turbocharger elements [4, 5, 6]. Since failures of turbochargers constitute 7-15% from the total amount of engine failures [7], there is a need to test a turbocharger using special benches under operating conditions. Thus, the improvement of the turbocharger testing bench and control of surge phenomena can prevent failures during maintenance [8].

In line with the above the objective of the study is to develop a method and bench for testing turbochargers of internal combustion engines based on the improvement of the lubrication process using a hydraulic accumulator.

2. Theoretical studies
From the theory of vibrations of elastic systems, we know that each of the natural frequencies of a system corresponds to the certain form of vibrations (its own vibration frequency) presented in Figure 1 [9].

![Figure 1. Amplitude dependence of vibration stresses σ, B from frequency f, Hz.](image)

In the theory of vibration processes the study of a resonance curve is of most interest. After obtaining a resonance curve we calculate it according to the formula:

$$\delta = \frac{\pi \cdot \Delta f}{f_p}$$

(1)

where $\delta$ is a decrement of vibrations; $\Delta f$ is width of the resonance curve at the level of vibrostresses 0.707 from the resonance one; $f_p$ is a resonance frequency.

Thus, the proposed method is one of the ways to measure the value of damping in any vibration system.

3. Research procedure
Based on the analysis of the literature sources and preliminary testing, we revealed that for excluding surge phenomena we need to conduct experimental studies. The rotor acceleration and spin-up produce a great effect on the compressor wheel with rapidly changing vibrations. During experimental studies we used a bench with a hydraulic accumulator. We improved the construction of the turbocharger testing bench by using real operational modes of a turbocharger on the bench and studying the limits of surge during tests (Figure 2). At present we are improving the construction of a bench taking into account the drawbacks of the previous variants of the testing bench [10].
The experimental studies included the check and control of the TCR geometry after critical testing on the bench. The tested object is a turbocharger rotor which consists of an aluminum compressor disk with blades and steel turbine shaft (Figure 3).

The research procedure of measuring the maintenance parameters of a turbocharger conducted after bench testing included the following:

- removing a turbine shaft with a disk;
- measuring the parameters of the turbine shaft and a disk before and after testing using Polytec CLV-3D Laser Vibrometer – three-component laser vibrometer. The wide dynamic range of CLV-3D, its high capacity and low level of noise allow its use in numerous modern applications. The measurement spot diameter of only 80 µm is much smaller than any other accelerometer footprint and allows measurement even on miniature components [11].

The process of testing presents the excitation of sinusoid vibrations with a gradual change of frequency on the personal computer in a profile program where analogue coordinate transformation takes place and real components of coordinates $x$, $y$ and $z$ are given. For measuring purposes, the rings were put on the turbine shaft. The rings were pressed tightly to the disk, thus we excited vibrations using these “rings” (Figure 4). The system consists of three-channel control unit of a laser vibrometer CLV connected with the optical sensory head of the CLV-3D, which contains three independent optical CLV systems, focused on the same measuring point at the distance of 310 mm from the front lens (Figure 4) [12-14].
Each output laser beam is bent at a 12° degree angle in reference to the surface, but it points at the measuring point from three different directions, divided at 120° degree angle of the output surface. The special photo paper 3x3 mm2 by size is attached to the tested object at the junction of laser beams (Figure 5a), the result is obtained by non-contact method with its help. Then we made different measurements of the turbocharger blades with a weight and without it. For making measurements we used weights 6 mm long and 5 mm in diameter, since they help detect local changes of the element (Figure 5b). The resonance frequencies of various elements of the turbocharger were defined in three planes.

4. Results of experimental studies
We removed the rotor of a turbocharger from the testing bench. According to the above mentioned research procedure we used the Polytec CLV-3D Laser Vibrometer. All the measured during the experiment data outputs were transferred to the three-channel data acquisition board and were processed by the computer. For external program calculations we used a regular program of the complex. We subsequently checked the resonance frequencies and vibration amplitudes of a turbocharger rotor. While processing the signals from the blade (with and without a weight), disk, turbine shaft and turbine the graphs demonstrate scattered peaks at the frequency of 9500 Hz and in the range of 12100 and 17479 Hz on the blade of the turbocharger wheel (Figure 6).

While conducting the experiment, we observed numerous vibrations of frequency peaks of the blades in different ranges – 2740, 3301, 6372, 6728 and 7196 Hz. Below we analyze the signals along the Z-axis since they demonstrate numerous peaks of amplitude vibrations. When we were measuring
the blades, the laser was located at the distance of approximately 310 mm and slightly higher, that is why there was practically no shift of the coordinate system. For presenting the total result we made measurements in different points of the turbocharger wheel.

4.1. Testing a blade

The blades of the compressor wheel were attached to the weights 5 mm in diameter except one blade where measurements are taken. The processing of signals is presented in the graph (Figure 7). Here we can see distinct peaks at the frequency of 6353 Hz and in the range of 10566 Hz, 12026 Hz and 14517 Hz.

The processing of signals when used with the weights is presented in the graph of Figure 8. Here one can see numerous peaks starting from the frequencies – 2721 Hz, 6447 Hz, 7177 Hz and finishing in the range of 9723 Hz, 12644 Hz and 14798 Hz.

4.2. Testing a minor impeller blade of a compressor wheel with a weight and testing the disk

The impeller blade of a compressor wheel is attached to the photo paper, then the laser approximation gets adjusted and the focus point is set. The processing of the signals is presented in the graph of Figure 9, where one can see distinct peaks at the frequency of 2740 Hz and in the range of 10641-14780 Hz. While testing the characteristics of a disk we obtained slight peaks of 1298, 2721 and 3283 Hz. Distinct peaks can be seen in the middle of the graph – 6353, 6690 Hz. Distinct peaks are also found at the end of the graph – 12195, 13843 and 14610 Hz (Figure 10).
5. Conclusions
Since a surge presents a process of pressure vibrations in a turbocharger and pressure line, the shaft load will vibrate as well, and subsequently in the flow there will occur upper harmonics or amplitude vibrations which can be recorded. The technique development recently enabled deciphering the specters of pulsations taking into account the multidimensionality of a task and flow distortions. The implementation of the constructed nodal element of turbocharging systems based on the conducted experiments and calculations helped considerably increase the effectiveness of engines as a result of improving the conditions of the release of gases from the cylinders and supply of turbocharger turbines.

The tests demonstrated that without taking complex measures separate elements of a turbocharger can be destroyed. Experimental studies measuring the pulsation parameters in the turbocharger rotor have shown peaks up to 14610 Hz.

The results obtained prove the applicability of the method in analytical studies. A turbocharger surge should be eliminated in further work from operational modes. The practicability of the given approach is fully confirmed by empirical evidence each characterized by its own frequency. In order to ensure the reliability of a turbocharger our further research will focus on the elimination of a surge phenomenon.

6. References
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