Geometry Monitoring of Rotating Parts of Power Unit with an Adapted Doppler Preprocessor

D V Kulikov, S V Dvoynishnikov, V V Rahmanov, V A Pavlov and I K Kabardin
Kutateladze Institute of Thermophysics, Siberian Branch of the RAS, 1 Ac. Lavrentyev Ave., Novosibirsk, Russia

E-mail: kulikov.dmitriy@gmail.com

Abstract. Current work is devoted to the development of a device for monitoring the dynamic shape of a power unit. The work is based on the FMCW method. The light source uses a low-coherence semiconductor laser diode. Signal processing is performed on an adapted Doppler processor. The paper describes the methods, hardware and signal processing algorithms.

1. Introduction
To date, at most power plants in Russia and the CIS countries, the decision on the need to adjust the shape of the stator and rotor of the generator is based on the results of measurements of their geometry in a static state [1]. At the same time, researchers note that the air gap between the rotor and stator in a running generator determined by the geometry can differ significantly from the gap in a static state [2–3].

The most adequate solution to the problem is based on semiconductor lidars [4–5]. In this case, the measuring part is located at a considerable distance in the area of low concentration of electromagnetic, vibration and temperature loads [6–7]. The purpose of this work is to develop methods for measuring increased accuracy, sufficient to detect deviations in the geometry of a rotating part in accordance with technological processes and unit designs in the power industry. Measurements should be made through a narrow ventilation duct in the stator body. The temperature in the area where the system is installed can reach 85 degrees Celsius.

The paper presents the development of a contactless distance meter to a moving surface based on a low-coherence semiconductor FMCW lidar [8]. The principle of operation of the FMCW lidar can be described by the following expressions.

Figure 1. Self-mixing effect in FMCW lidar, occurrence of the beat frequency $\Delta f$.
The optical frequency of the radiation is modulated by a signal of a certain frequency. The radiation is divided into probing, directed to the object, and reference, which is used as a local generator. When it hits the object, the radiation is reflected and part of the scattered radiation gets back into the semiconductor laser. If the emission frequency of a semiconductor laser is delta-modulated during the passage of radiation to the object and back, the frequency changes by $\Delta f$. (Figure 1) Being scattered by the surface of the rotor or stator, the radiation is mixed with the emitted radiation in the body of the glow (laser).

By analyzing the signal from the photodiode, we obtain the beat frequency of the probing and scattered radiation. The speed of the object moving in the direction of the beam $v_t$ and the distance to the object $D_t$ are related to the beat frequency $\Delta f$ and can be calculated from:

$$f_R = \frac{f_1+f_2}{2} = \frac{4D_t\Delta f}{c+T_{mod}},$$  \hspace{1cm} (1)$$

$$f_D = \frac{f_2-f_1}{2} = \frac{2v_t}{\lambda},$$  \hspace{1cm} (2)$$

where $\lambda$ is the wavelength and other symbols are defined in Figure 1.

The implementation of a laser device for monitoring the geometry of rotating parts of power plants requires the creation of methods for processing the received signals. Data processing should contain the following main stages:

- calculation of distances to the rotor surface,
- signal processing of the rotor speed marker,
- phase averaging over several revolutions,
- averaging over the points of the pole.

The developed measuring complex is based on the use of a Doppler preprocessor and a hardware interface module. This solution allows expanding the scope of application of laser Doppler preprocessors for related technical problems.

2. Doppler processor

To achieve this goal, a Doppler preprocessor of the LAD-05 anemometer was used in the work, and a hardware module for interfacing the preprocessor with an FMCW lidar and algorithms for digital signal processing were developed.

![Figure 2. Laser Doppler preprocessor structure semiconductor anemometer LAD-05.](image-url)
controlling the PMT gain synchronously with signal processing. The exchange of service information between the personal computer and the processor of the ARM family is carried out by another specialized pipeline, along with the transfer of data from the preprocessor by switching Ethernet packets.

The 32-bit processor of the ARM family has service functions for configuring the programmable logic chip, transferring the configuration (firmware) file and preprocessor settings files via the high-level FTP protocol. The ARM processor uses the SNMP protocol to diagnose the operation of all optoelectronic modules in the device by measuring voltages, currents and temperatures at critical points. The processor core runs Linux operating system at a clock speed of 180 MHz and can achieve a performance of 200 MIPS.

3. Preprocessor and lidar interface module

The Doppler preprocessor of the described anemometer required adapting of the hardware for monitoring the geometry of the rotating parts of power plants. Preprocessor was supplemented with hardware module interface and processing FMCW-lidar signals (Figure 3), comprising the following components:

- a specialized pipeline for controlling digital-to-analog converters and laser protection elements synchronously with the preprocessing of the measured signal (implemented on the EP3C25 FPGA from Altera in the preprocessor module);
- DAC on IC AD5321, 12-bit for controlling the value of the upper level of the laser current;
- DAC on IC THS5671 14-bit for the formation of the modulating sawtooth signal (generated by a specialized pipeline in the FPGA preprocessor);
- DAC on IC AD5321 for setting the laser stabilization temperature;
- laser current generator for a current of up to 140 mA, controlled from a DAC and created on a low-noise operational amplifier with a bandwidth of up to 60 MHz;
- laser current protection comparator, the signal of which is used in the logic of a specialized pipeline in the FPGA preprocessor to control the laser protection keys (protection operation is controlled by a PC);

The adapted preprocessor has the following main parameters.
- Adjustment range of the static current of the laser diode: 0-140 mA.
- Range of adjustment of the modulating current of the laser diode: 0-45 mA.
- Frequency of modulating current: 1000; 500; 250; 125 Hz, etc.

The suppression of the fundamental laser modulation frequency in the photodiode signal is carried out by active high-pass filters on two low-noise operational amplifiers. The signal from the amplifier output is fed to the preprocessor for further processing.

![Figure 3. The structure of the module for interfacing the preprocessor with the FMCW lidar.](image-url)
4. Processing data of FMCW lidar

FMCW lidar data processing by the Doppler preprocessor is performed as follows. From the interface module for processing, data is received from four ADC channels, which are sampled signal from the laser photodiode (CH1 Figure 4), the modulation signal of the laser diode (CH2 Figure 4), TTL modulation signal of the laser diode (CH3 Figure 4), and RPM sensor signal (CH4 figure 4). At the first stage, the signals of the measuring module are converted as follows. The signal from the photodiode is divided into sections corresponding to the modulation period of the laser diode. The spectrum is calculated for each half-period. Each spectrum contains the frequency with the maximum power. In accordance with formula 1, the frequency proportional to the distance is equal to the half-sum of the frequencies with the maximum power in the first and second half-periods.

The signal contains amplitude modulation and frequency nonuniformity and, as a result, several fundamental frequencies in the spectrum, which is due to the low coherence of the semiconductor laser and the change in the mode composition upon modulation of the pump current. To increase the accuracy, the signal processing is supplemented with window filtering in the frequency domain.

The marker signal processing algorithm uses the calculation of the period as the maximum of the autocorrelation function. The coordinate of the second maximum in the autocorrelation function is equal to the period of the synchronization signal.

Phase averaging is realized by creating synchronous arrays, where one array contains data on the marker phase, and the other contains the calculated distances to the rotor surface of the power unit.

Averaging over the points of one pole is carried out in order to build a diagram of the shape installed at power plants. For this, at each pole of the phase-averaged diagram, we have selected samples that certainly belong to the surface of the pole, rather than to its edges or subpole. As a result, the surface of the rotor poles deviates from the average in mm (Figure 5).

Investigations of the photodiode signal when measuring the distance to a fixed surface are carried out, and the effects arising from the use of a low-coherence laser diode are shown. The proposed algorithm for calculating the distances to the rotor surface allows reducing the error of the results to 1.5%.

![Figure 4. Discretized signals from the laser photodiode.](image)
Conclusions
Lidars based on vertical-structure PH85-F1P1S2 laser diodes (8mW; 20mA; 850nm) and ADL65401 laser diodes (50mW; 100mA; 850nm) have been realized on the basis of the developed preprocessor. The results of the lidar tests have confirmed the reasonableness of the chosen architecture and the flexibility of its use. The preprocessor of the laser Doppler semiconductor FMCW lidar has been successfully used in the system for monitoring the geometry of the loaded rotor of super-powerful hydroelectric power plants.

Methods have been developed for measuring the geometry of a rotating unit in accordance with technological processes and unit structures in the power industry. A hardware module for interfacing the LAD-05 anemometer preprocessor with an FMCW lidar has been developed. Adaptation of the hardware required the addition of a module to the circuit; 5 DAC, current generator, laser photodiode current amplifier, protection circuit and filters for signal frequency. The algorithms for processing the RPM marker signals have been implemented. As a result, phase averaging of signals is applied to visualize the measurement results of rotating parts of power plants.

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Figure 5. Deviation of the surface of the rotor poles from the average in mm.