Analysis of modern measuring instruments for research diagnostic systems of print media equipment

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Abstract. The quality of printing products substantially depends on the accuracy of the individual mechanisms of the printing equipment. Since technological processes usually last in a period of a second, conventional measuring instruments turn out to be too inertial; therefore, to detect deviations of the given parameters (loads, locations, accelerations) from the calculated values, various sensors are used. The work is devoted to the selection of diagnostic tools for typical measurements used in print media equipment on printing equipment. Possibilities of parallel measurements and mutual analysis of signals of the designed diagnostic systems for research of parameters of the equipment of the print media industry are considered.

1. Introduction

In the process of scientific research work on the study of the structural and diagnostic parameters of printing machines, the following aspects remain relevant: control, diagnostics and monitoring of the state. Diagnostic tools in the printing industry are used to identify defects in the certification of technological machines, to assess the condition of machines during operation and, as a result, to prevent the occurrence of technological defects in the products manufactured by these machines. Monitoring the technical condition, assessing the margin of stability, wearing process, reliability, classifying states, separating vibration sources, determining the dynamic characteristics of mechanical systems is an important list of tasks that modern diagnostic methods solve for complicated designs of printing machines, including electronic equipment and automated systems for auxiliary operations [1]. However, the organization of scientific research within printing houses can face the following difficulties:

- modern printing equipment operated at enterprises is imported and serviced by specialized companies. Statistical data on failures, causes of defects are not always open information;
- variation of variables during testing and experiments in the production process can lead to technological defects, which is unacceptable in commercial printing;
- experimental research requires strict adherence and repetition of the operating mode of the research object, repeated starts, changes in technological loads. These requirements are difficult to achieve in businesses involved in commercial printing due to the variety of alternating runs during the print shop shift;
- withdrawal of the printing machine from the production process specialized for research is difficult due to economic costs and the continuity of the organization of the production process. This is difficult in large printing houses where modern equipment is used.
Therefore, in the process of scientific research work on the study of the states of mechanisms of printing machines, measurements of parameters are carried out both on the installed technological equipment [2] in educational institutions, and on specially made layouts of nodes and stands [3–9], software packages are also widely used [10–12]. The purpose of this work is the selection of components for external diagnostics of the parameters of printing machines and the presentation of an example of their use in research work.

2. Problem statement
The research objective for achieving the goal is the allocation of diagnosed parameters of printing machines, the selection of modern components of measuring instruments (sensors) and accompanying software with research objects as an example and description of the possibilities of using such systems.

3. Preparing initial data and solving the problem
In the research practice of print media equipment, the following indicators have been studied for the last decade: register accuracy and print quality [12, 13]; study of the parameters of the air bars [14, 15] and the counter stackers of feed roll-type presses [16], the parameters affecting the quality of stitching [6], the dynamic and kinematic characteristics of the automatic book trimmers [2, 10, 11, 17], the accuracy of operations for block processing, etc.

Based on the analysis of the publications of the studies carried out, we will single out the main diagnosed parameters of the machines in the print media industry and give examples of objects to be diagnosed and select the diagnostic tools in table 1.

| Parameters and measured values | An example of a diagnostic object | Diagnostic tools |
|--------------------------------|---------------------------------|-----------------|
| 1 Positioning accuracy of semi-finished products processing mechanisms when they are stopped in working position.  
  • angular arrangement;  
  • mutual arrangement of the working mechanisms and positioning at the origin. | • the relative position of the sewing machine table and the carriage with sewing tools with threads (hooks, needles, piercing devices);  
  • positioning of the stamp relative to the table with the lid in the gilding press. | • incremental or absolute encoders;  
  • angle encoders;  
  • mechanical and electronic edge finders;  
  • inductive proportional sensors. |
| 2 Identification of vibrations of working bodies.  
  • linear arrangement;  
  • distance to the object of study. | • vibrations of the cylinders of the printing pair, causing unevenness of the onslaught, the appearance of stripes on the print, both free standing and periodically repeating.  
  • vibrations of the inking unit rollers causing uneven ink layer on the printing plate and position on the print. | • inductive proportional sensors;  
  • eddy current;  
  • optical;  
  • capacitive sensors. |
| 3 Identification of vibrations | • vibrations of the grabber. | • accelerometers; |
in the drive of the working links:
- vibration acceleration;
- linear arrangement;
- location in space.

4 For measurements of high-frequency vibrations in the drive printing machines:
- vibration acceleration;
- location in space.

- vibrations and defects of gears, rolling bearings, couplings.
- piezoelectric; IEPE;
- piezoresistive accelerometers.

5 To control the efforts of the working bodies:
- elastic and plastic deformation of the working bodies of the drives.

- efforts in the drive of the side knives of the three-knife trimmer;
- the forces developed by the clamping one-knife trimmer.
- strain gauges;
- optical (laser) sensors.

6 Time control of individual processes (individual sections of the kinematic cyclogram):
- the time of the processes.

- the time interval between the steady-state pressing force of the block and the force of the preliminary pressing of the feeder of the operating unit of the three-knife trimmer.
- mini oscilloscope;
- oscillogram in the LabView system.

7 Measurement of distances when detecting surface contours, deformations, when scanning a profile (2D):
- linear measurements of the location of the investigated object.

- the beating of the surface of the rubberized form inking roller relative to the printing machine frame;
- the beating of the surface of the damping brayers relative to the printing machine frame.
- optical (laser) sensors;
- triangulation sensors;
- conoscopic sensors;
- confocal sensors.

The positioning accuracy of semi-finished products processing mechanisms when they are stopped in the working position affects the quality of the products. Interacting pieces of equipment can be located on massive metal parts. In this case, inductive proportional sensors are most suitable for measurements, such as: E2A-S08KS02-WP-B1, VIKO-I-M12 (figure 1).

When choosing sensors, you should pay attention to the following technical characteristics:
- sensitivity (how many volts of the output signal correspond to 1 mm of displacement);
- polling frequency;
- range of measured displacements.
To detect the vibrations of the actuators, you can pre-install a fixed base with a calibrated gap. For example, to measure the oscillation of the cylinders of the printing pair, connect the reference surface with the bed and the surface of the cylinder. In this case, inductive proportional sensors BESM08MI-PSC15B-BV03, BESM08MI-PSC20B-BV03 are suitable for measurement (figure 1). But for measuring the vibrations of the surface of rubberized form inking rollers or dampening devices, the sensors listed above are not suitable. In this case, it is recommended to use optical sensors [18].

Requirements for technical characteristics for measuring oscillations of actuators are higher, since it is necessary to carry out measurements with an error not exceeding 0.01 mm, with a period of 0.002 sec, so as not to miss oscillations with a frequency of up to 250 Hz. The instability of the position of the working mechanisms (see item 1, table 1) can be caused by vibrations in their drive. To detect such oscillations, it is advisable to use accelerometers ADXL78, ADXL203, ADXL345BCCZ (figure 2), operating in the frequency range from 0 Hz and capable of measuring the constant component of accelerations.

The most important characteristic of such accelerometers is the range in which their signal is proportional to the acceleration. It is known from the theory of accelerometers that with approaching the natural frequency, their signal may increase disproportionately, therefore, damping devices and filters are used in accelerometers. The frequency range of such accelerometers does not exceed 200 Hz. Another important characteristic of accelerometers is sensitivity (signal value in Volts, when acceleration occurs 1 m/s²).

For the study of high-frequency oscillations in the drive of printing machines, piezoaccelerometers TM0786A-M-S, TM0786A-M are recommended (figure 3). These diagnostic tools make it possible to assess the magnitude of the vibration amplitude caused by disturbances in the macro and microgeometry of the contacting teeth in gear drives, as well as by pitting corrosion in rolling
bearings. They are distinguished by a wide frequency range (up to tens of kHz) of measured accelerations and high sensitivity, but their low frequency limit starts from a few Hz and they are not able to measure the constant component of the signal.

Figure 3. Piezoaccelerometer.

The control of the efforts of the working bodies, the amount of tension and compression, bends and other deformations of the working bodies of the mechanisms can be estimated by measuring the amount of stress obtained from the Wheatstone measuring bridge and converting it into the required value by pickup calibration. For this measurement, strain gauges are suitable FKM 30-200, FKPD 5-200, 2PKB 20-200GB, 2 FKPA 5-100GV, fixed directly on the linkage rods of the mechanisms of printing machines (figure 4).

As a load meter, you can use the dynamometer bracket, on which the strain gauges are glued.

Figure 4. Strain gauge.

Time control of individual processes (in separate sections of the kinematic cyclograms). Technological operations in most printing machines follow each other at a certain time interval [19]. For example, the working clamping pressure before starting to cut a block in a three-knife trimmer should occur after the preliminary clamping pressure is reached. This is necessary to remove air between the sheets of the block and improve the cutting quality. You can control the time lag by recording (figure 5) the clamping pressure obtained by the method specified in paragraph 6 of table 1.
High-precision measurements of the distances to the surface, deformations, when scanning the profile (2D) of the surface of the working bodies, require high speed and accuracy from the optical sensor [19] (figure 6). The following types of optical (laser) sensors are used in measurements:

- triangulation sensors;
- conoscopic sensors;
- confocal sensors.

Laser sensors are characterized by high measurement accuracy (some models allow measuring deformation values less than a micrometer OADR 20I6465/S14F, OADR 20I6565/S14F. Optical sensors allow large angles of incidence of the laser beam on the surface, up to 170 ° [21,22]. The report rate of the sensors reaches 3 kHz, and additional lenses will allow you to expand the ranges of operation on the same laser sensor. Such sensors allow measurements to be made on a translucent material [23].

Measuring path. Signal cables connecting sensors with an analog output signal should be as short as possible and shielded to reduce the influence of electromagnetic waves.

The signal coming from the sensors must be converted from analog to digital form — for recording, visualization and further processing. Load cells require a separate power supply and a special wiring diagram.
Analog-to-digital converters are used for conversion. An example would be the NI hardware equipped with the LabView software (figure 7), built on the principles of structured programming.

If the sensors have a serial interface RS485/422, you will need to connect the OPC server to the LabVIEW system, as well as a converter of RS485/422 interfaces to USB. A large number of blocks provided in this system allow not only visualizing and recording signals received from sensors, but also performing preliminary processing (filtering, multiplying by coefficients, adding, etc.).

4. Discussion of results
The use of several types of sensors simultaneously makes it possible to obtain more data and improve the accuracy of measurements of physical quantities. Let us give an example of the application of parallel measurements and mutual analysis of signals of designed diagnostic systems for researching the parameters of printing machines.

For experimental development of the damping unit circuit and determination of the parameters of the formation and transfer of the solution layer on the conductor cylinder, a measuring system with capacitive and inductive sensors and a NICdaq-9178 data collection unit from NationalInstruments were tested, connected to a personal computer with the LabVIEB 8.2 program (see figure 7). With the help of the data taken from the readings of the sensors (figure 8, table 2), two torsion graphs of the dependence of the layer on the signal magnitude (figure 9 and figure 10) were built, with the help of which it turned out to find out the coefficient of the sensors. Calibration curves of the dependence of the layer on the signal strength of the inductive sensor and the capacitive sensor helped to determine the coefficients of each sensor.
Figure 8. Measuring system with capacitive and inductive sensors on the model of the damping unit.

Table 2. Measurement data from the sensors.

| Inductive sensor (V) | Capacitive sensor (V) | Flap shaft displacement (mm) |
|----------------------|-----------------------|-----------------------------|
| 5.47                 | 4.54                  | 0.00                        |
| 4.72                 | 4.44                  | 0.05                        |
| 4.48                 | 4.42                  | 0.08                        |
| 6.07                 | 4.63                  | −0.05                       |
| 6.41                 | 4.66                  | −0.08                       |

The correlation coefficient of the inductive sensor is 0.99 and that of the capacitive sensor is 0.98. The root-mean-square deviation was $\sigma = 0.07$ for an inductive sensor, and for a capacitive one, $\sigma = 0.017$. Thus, the total deviation was $3\sigma = 0.033$ mm. The calibration curves of the layer dependence on the signal value are shown in Figure 9–10.

Figure 9. Inductive sensor coefficient.
In the research work to study the influence of the gaps in the kinematic pairs of the side knife drive mechanism on its operation, a measuring system was tested and implemented to control forces and accelerations using a combination of strain gauges and accelerometers. The measurements were carried out on a 3BRT 125/450 three-knife trimmer. To study the longitudinal thrust forces, two wire strain gauges were installed. In the LabVIEW program, the readings of the strain gauges were converted to relative units of elongation. To read the value of only longitudinal deformation, the sensors were placed on opposite ends of the linkage rod, opposite each other (figure 3). Sensors positioned in this way compensate for bending, as when bent, one of the sensors stretches and the other contracts. The operating peculiarities of such a strain gauge arrangement is shown in figures 11–12.

**Figure 10.** Capacitive sensor coefficient.

**Figure 11.** The used layout of the strain gauges on the linkage rod. 1, 2 — strain gauges; 3 — linkage rod; F1 — useful power; F2 — bending force.
Figure 12. The operating peculiarities of the used arrangement of strain gauges on the linkage rod. R1, R2, R3 — resistance of the resistive measuring bridge, Rt1, Rt2 — resistance of the strain gauge, V — signal output, V.

The strain gauges were calibrated by applying a lever to the slider with a certain force F and then fixing the readings of the linkage rod deformation k1 (under the action of F) and k0 (no load) on the graph in the LabVIEW program [24].

It was found that the relative unit of deformation corresponds to 1666·10⁵ N. Also, during the calibration process, it was found that when the linkage rod is compressed, the graph in the LabView program increases, and in the process of stretching, it decreases.

Simultaneously with the measurement of deformations in the linkage rod, the indicators of the acceleration of the slide by the accelerometer were recorded. An ADXL78 accelerometer from Analog Devices was used to measure the acceleration of the slide. The accelerometer was mounted on the right knife holder in a direction parallel to the slide rails.

The accelerometer signal is transmitted to the data acquisition unit (in Volts). In order to convert Volts to m/s², the accelerometer was pre-calibrated. Thus, one volt corresponds to 48,8 m/s². To collect data, we used an NI cDAQ-9178 unit from National Instruments, connected to a personal computer with the LabVIEW 8.2 program.

In the LabVIEW program, a scheme was drawn up for collecting data from a strain gauge and an accelerometer [25]. To smooth the received signals from the sensors, the scheme provides a smoothing filter with a rectangular window with a half-width of five measurements. The report rate of the sensors was 100 Hz.

Examples of data obtained by the measuring system are shown in figures 13–14.
5. Conclusion
The use of sensors for researching the parameters of equipment in the print media industry allows finding the causes of defects in the operation of equipment, assessing the speeds of the main elements of the machine and their acceleration, analyzing the transient processes that occur during the operation of the mechanism in motion and at a standstill, which in turn contributes to an increase in product quality. It is advisable to use computer technology with a graphical interface (MatLab-Simulink, LabView) for calculation operations.

Parallel measurement of several dynamic indicators of mechanisms not only allows you to avoid random errors, but also to evaluate parameters such as the amplitude of oscillations in the drive, the effect of clearances, to evaluate technological and inertial loads separately, which can be useful in
identifying the causes of equipment operating defects and its diagnostics, which can improve the quality of regulation, optimize technological processes, improve the availability coefficient of technological machines, improve existing technological equipment, increase the productivity and reliability of technological machines and solve other problems of automation of technological processes.

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