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THE INFLUENCE OF CHANGES IN THE ROTATIONAL SPEED OF THE SHAFT JOURNAL SLIDE BEARING ON THE ACOUSTIC EMISSION SIGNAL

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Abstract

The paper presents preliminary studies of a slide bearing operation by using an acoustic emission. These studies were designed to test the usability of this method for the diagnosis and monitoring of bearings in marine drive system (in particular, stern tube bearing). This paper proposes a method of testing the operating status of the slide bearing using acoustic emission. It discusses the research station, where the study was conducted. The authors paid special attention to the impact of rotation speed of the shaft journal bearing sliding to change some parameters of the acoustic emission signal. The gathered results were analysed and it was evaluated how the rotational speed of the shaft journal affects the individual signal parameters of acoustic emission. Additionally, the sensitivity of the method was evaluated. The article describes: the basics of testing with using the acoustic emission, parameters of the acoustic signal (the acoustic emission burst count, arrival time, duration time, signal amplitude, signal energy and RMS) and the equipment necessary for measurements by using this method. This method, unlike the ultrasonic testing detects only the active wave source, and it is very sensitive to detect changes in the moment when the installation is operating under load. It proposes to use the acoustic emission method to study operational conditions of a slide bearing. Slide bearings are used in many constructions of mechanisms, machines and equipment. They are a strategic element of their design and their improper work leads to the machine damage in a very short period of time, which automatically excludes it from further exploitation. For this reason, the correct assessment of the technical condition of slide bearing and knowledge of the current operating conditions of the slide bearing are extremely important (particularly in the case of bearings in marine propulsion system).

Keywords: *non-destructive testing, diagnostic, acoustic emission, slide bearing*

1. Introduction

The Acoustic emission is the technical term for the phenomenon, which includes generation and propagation of temporary elastic waves. These waves are the result of a sudden release of the energy accumulated in the material or they are caused by the process. The acoustic emission could be divided into two types, i.e.: a burst emission and a continuous emission. In the burst emission, duration time of a burst signal is shorter or equal to the interval time between pulses (Fig. 1a). In the continuous emission, the duration time is longer than the interval time between pulses (Fig. 1b). The sources of burst emission are: the emergence and development of microcracks, cracks, twinning, etc., whereas the continuous emission is generated by moving dislocations related with plastic deformation, reconstruction of solid microstructure, movements of the elements in the test medium combined with friction, as well as the energetic and biological processes [2-4].

2. Acoustic emission basics

The acoustic emission method is one of the NDT methods and formulated in the PN-EN ISO 9712: 2012 [4]. The guiding standard for describing the general principles of research by using this method is PN EN 13554: 2011 [5]. It is based on the recording of elastic waves, which are generated by the release of elastic energy accumulated in the material. This is the result of changes in the energy balance of the system. In other words, we can say that they are formed as a result both of the micro and macro structural changes in the material. The factor that causes release of energy as well as the formation of elastic waves is a physical process, e.g. mechanical stress, thermal stresses, environmental impact or chemical process [2]. The typical acoustic emission frequency range is usually determined in the range of 2 kHz – 2 MHz [6].

a) *b)*

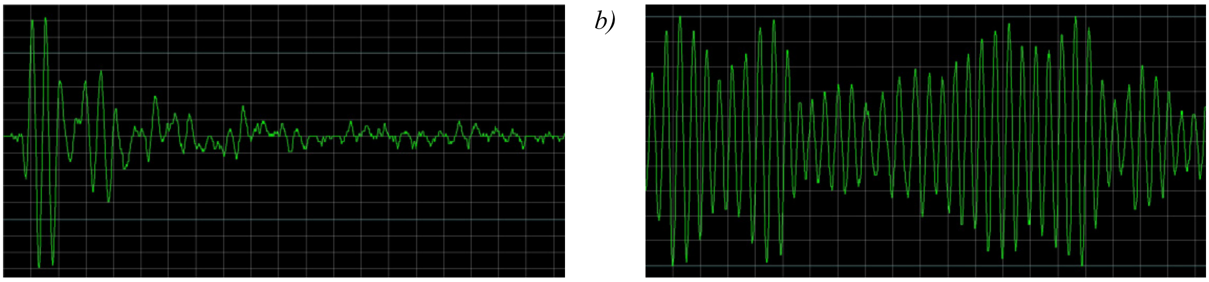

Fig. 1. Example of acoustic emission signals: a) burst signal; b) continuous signal

In order to allow evaluation and comparison of acoustic emission signals, it is necessary to know the basic characteristic parameters of the signal (Fig. 2). These were included in the PN-EN ISO 1330-9: 2009 and are composed of [7]:
- arrival time (absolute time of first threshold crossing),
- the number of hits,
- the maximum amplitude of the burst signal,
- rise time (the time interval between the first threshold crossing and maximum amplitude),
- signal duration (the time interval between the first and the last threshold crossing),
- the number of threshold crossings,
- signal energy (the integral of the square of the amplitude over the signal duration. In some cases, to determine the signal energy is used the envelope of the burst signal, called Marse energy),
- RMS (Root Mean Square).

The biggest advantage of the acoustic emission is the possibility of very early detection of microchanges in the material structure or very slow enlarging of defects in the material. This is very difficult or impossible by using other methods. Another positive feature of the described method is the opportunity of recording processes in the large volume of the test piece. The sensitivity of this method is so high, that it allows monitoring and detecting the acoustic emission signals using a relatively small number of sensors, mounted on the tested structure. It is also possible to test appliances and structures periodically or continuously without excluding them out of operation. Another advantage is the possibility of fault location by using multichannel measurement systems. To locate the source lying on a straight line, a two-channel system is required and to locate the source lying on the plane, a four-channel system is necessary. The source location is normally done by the method of triangulation based on signal the arrival time difference Δt. The difference in distance between the source and the various sensors are equal to the arrival time differences of the signals to each sensor with the speed of the elastic wave. This time is measured for each transducer, and these are necessary for triangulation input source location algorithm [1].

The essential drawback of the acoustic emission method is the necessity of a very complex signal processing. Many difficulties are generated by the wide range of the frequency spectrum of the acoustic emission signals, depending on the test material. Necessary for the analysis is the necessity of recording the amplitude and the duration of the signal from microseconds to tenths of a second. Another disadvantage is the presence of very weak signals, which are often disturbed by background noise. In order to minimize their impact it is necessary to use filters to cut out noise and the acoustic isolation of the measuring device. Another negative feature of the described method is deformation of the signal caused by damping of the material and multiple reflections from the boundaries of the material. This is due to the fact that the source of the acoustic emission signal is inside the material and the receiver is placed on its surface.

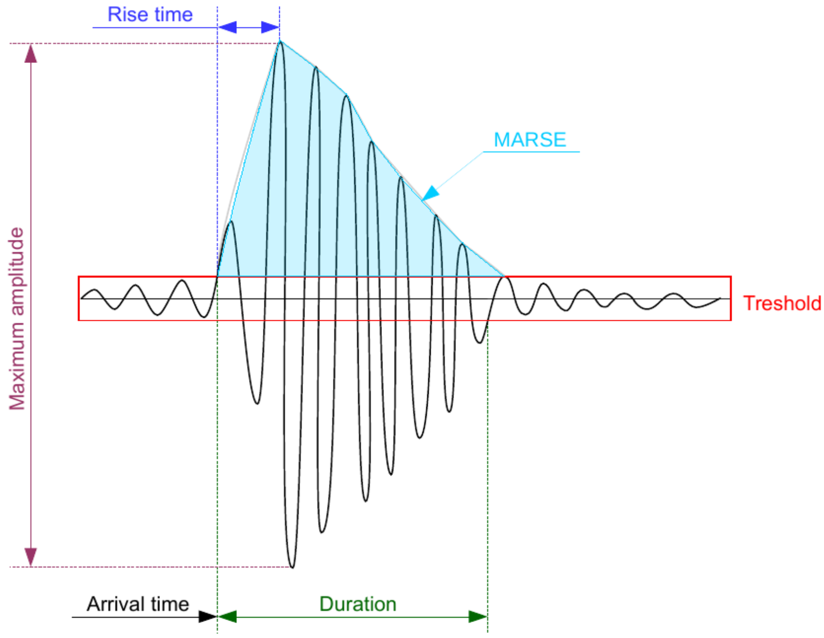

Fig. 2. Example of burst emission signal with characteristic parameters

3. Acoustic emission measuring chain

Figure 3 shows a block diagram of the measurement chain used for the measurement of acoustic emission starting from the material coupling and ending with the computer software.

Piezoelectric sensors, used during testing, should have a selected optimum frequency range. It should be selected depending on the intended type of the acoustic emission source and the material from which the tested structure is made. It determines the propagation conditions and damping of the wave. During the test of steel structures, the sensors operating in the range 100 – 300 kHz are normally used [9].

Preamplifiers are part of a measuring chain for measuring acoustic emission signals. They typically include one input for receiving a signal from the sensor, and one output, which is connected to the acoustic emission signal processor. The signal coming from the sensors is a signal of the high impedance and is not suitable for transmission through long cables. For this reason, preamplifiers convert the high-impedance input signal to a low impedance signal. The effect of this procedure is the minimization of loss during signal transmission through long cables. Furthermore, preamplifiers enhance the signal from the sensor to the voltage corresponding to the signal processor. These elements of the measurement chain are so designed as to maintain the highest possible signal-to-noise ratio. This is caused in order to minimize the desired signal interference. Preamplifiers can be integrated with acoustic emission sensors, or may be a separate element of the measuring chain. [10]

Other elements of the acoustic emission measuring chain are filters. Signal filtering is necessary to avoid interference and remove from measuring channel unwanted components of the acoustic emission signal frequency, which result from the noise. Currently, digital filters are commonly used since they are highly flexible and the filtration process is completely repetitively [10]. During the testing with using acoustic emission it is possible to apply low-pass filters – LP, high-pass filters – HP and the band pass filters – BP.

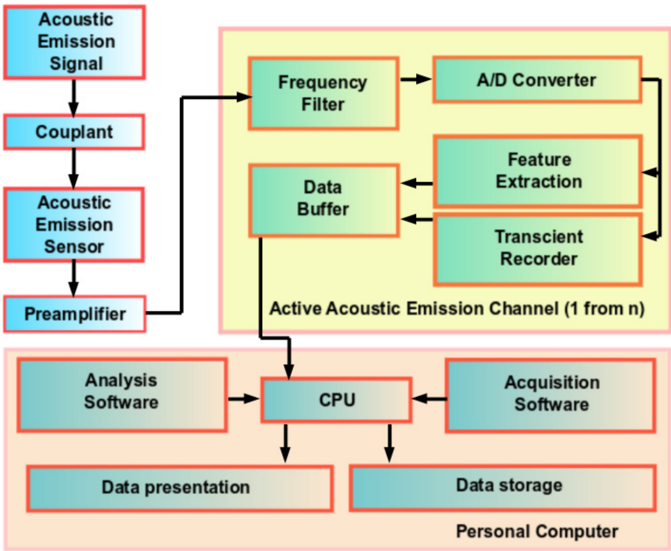

Fig. 3. Block diagram of the measurement chain used during acoustic emission testing

Analogue-digital converters (A/D) have a 16-bit dynamic range. Their continuous sampling frequency is 10 MHz, which entails the production of 10 million measurements per second for each channel. These data is processed by the processor (function of extraction) in real time. Transition recording is used to archive all samples of the waveform of such a burst signal, which characteristics are significant [9].

4. Methodology of research

The preliminary study was carried out on the bearings test stand with hydrodynamic lubrication, which is located in the Faculty of Mechanical Engineering at the Maritime Academy in Gdynia. The Fig. 4 shows a test stand. It consisted of a steel shaft *1*, which journal is rotating in bushing *2* made of bronze. The rotary motion of the shaft is carried out by a belt transmission *3* drive by a DC electric motor *4*. The change of the engine speed was realized through the thyristor system. For the measurement of engine speed, a tachogenerator was used. Changes in load of a bearing were achieved by using a mechanical actuator *5*. While conducting the experiment gear oil "TRANSOL SP 100" was used.

a) b)

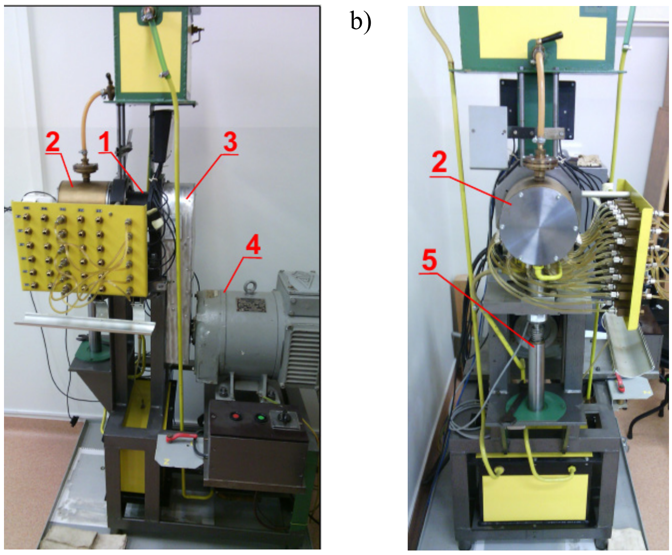

Fig. 4. Test stand: a) front view, b) side view

Measuring device AMSY-6 from Vallen-Systeme GmbH was used to carry out the experiment. This device is equipped with four parallel measurement channels. For every two channels there is one acoustic signal processor ASIP-2/S. It is equipped with a data-recording module of 8MB per channel. Preamplifier AEP4 was connected to the measuring device by the BNC cable. It operates in the frequency range of 20 kHz – 1 MHz with a gain of 34 dB. Another element of the measuring chain was a piezoelectric sensor VS150-M for measuring the acoustic emission signal. It operates in the frequency range of 100 – 450 kHz. The sensor was attached to the bearing with the handle made by the authors. The Fig. 5 shows a location of the sensor. The silicone lubricant was used as a coupling agent between the bushing and the sensor.

The research consisted in measuring the acoustic emission generated by a rotating shaft in the bushing in variable operation conditions. The measurements of the various parameters of the oil lubricating film were carried out in a variable speed of the shaft journal and a variable bearing loads. The purpose of the authors was to determine the impact of changes in the rotational speed of the slide-bearing shaft on the acoustic emission signal.

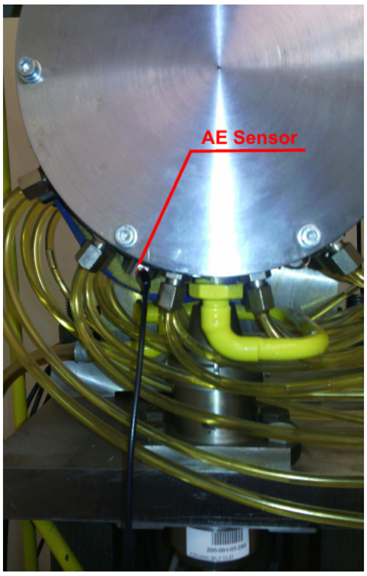

Fig. 5. Location of the sensor

5. Analysis of the results

During the execution of studies, the acoustic emission signal generated by the shaft journal, rotating in the bearing bushing, was recorded. In the beginning acoustic emission signal of the unloaded bearing, rotating at a speed of 270 rev/min was recorded. This measurement allowed setting the threshold level, which allowed eliminating part of the noise related to the environment. Subsequently the bearing load was increased to 1000 N, then to 2000 N, and finally to 3000 N. For each bearing, load acoustic emission signal was registered. For the speed of 400 rev/min, 600 rev/min, 800 rev/min and 1000 rev/min measurements were made by the same scheme.

The second part of the studies consisted in analysing signal parameters, recorded by using Vallen Visual AE, which include amplitude, the number of events and the RMS. For each measurement, an average amplitude, amplitude scatter and the average RMS value were calculated, as shown in Tab. 1.

Analysing the data shown in Tab. 1, we can see that the changes in the speed of the slide-bearing shaft are the most intensely represented by changes in the amplitude of the acoustic emission signal (Fig. 6a). RMS change significantly shows the changes of the shaft rotation. At lower rotation speeds, the increase of the RMS is small, but with the increase of the bearing rotational speed it is significant (Fig. 6b).

Tab. 1. Mean values of amplitude (A), the dispersion of the amplitude (R) and average of the RMS recorded acoustic emission signals

Revolution [rev/min]	Load [N]	A [dB]	R [dB]	RMS [uV]
270	0	48.99	5.30	71.36
270	1000	52.19	4.10	105.03
270	2000	52.21	6.40	105.77
270	3000	51.91	3.40	94.86
400	0	58.98	11.30	122.61
400	1000	61.11	6.40	82.20
400	2000	59.98	3.00	81.99
400	3000	57.62	7.50	119.80
600	0	68.84	4.10	139.40
600	1000	69.10	4.10	142.90
600	2000	68.15	3.00	159.60
600	3000	66.68	2.70	134.60
800	0	75.54	4.50	227.00
800	1000	72.83	1.90	295.70
800	2000	72.59	1.90	260.90
800	3000	71.42	2.60	242.30
1000	0	75.63	3.80	379.70
1000	1000	77.20	3.80	387.90
1000	2000	77.12	2.60	399.60
1000	3000	75.96	1.90	382.10

a) b)

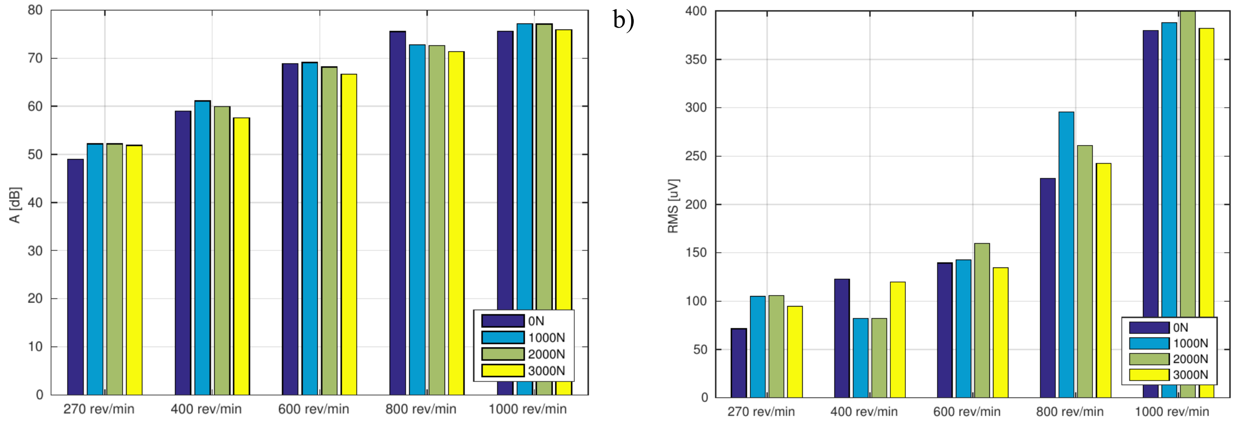

Fig. 6. A plot of the: a) amplitude (A) vs rotational speed (n) of the shaft for various bearing loads, b) RMS vs rotational speed (n) of the shaft for various bearing loads

Another analysis was statistically calculated the influence of the shaft rotation speed changes to changes of amplitude and RMS. It was carried out at a confidence level of 95%. The calculations were done by multiple regression and showed that the slide bearing journal rotational speed changes significantly alter the acoustic signal. This is shown in both the changes of the signal amplitude, as well as changes in the value of RMS. The scatter plots of amplitude versus revolutions (Fig. 7a) and RMS versus revolutions (Fig. 7b) perfectly illustrate this. The plots of the predicted values versus observed values for the amplitude (Fig. 8a) and RMS (Fig. 8b) were also presented.

For the above data there were also determined the correlation coefficients. In case of dependence between amplitude and revolutions the correlation coefficient was r=0.964. This shows that the relationship between these two values is very strong. However, correlation coefficient between RMS and revolutions was r=948. This means that a change of RMS equally strongly reflects the change in the revolutions.

a)

b)

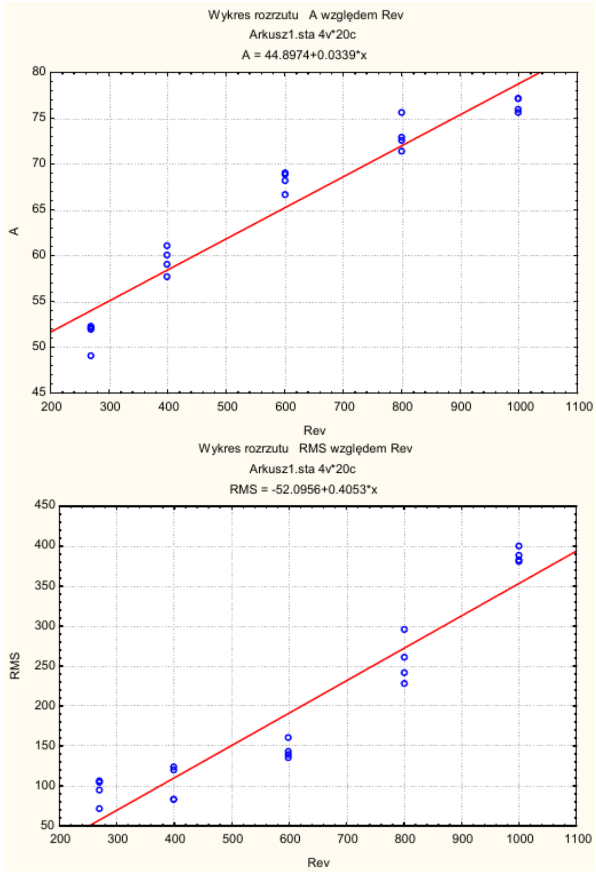

Fig. 7. Scatter plots of: a) amplitude vs revolutions, b) RMS vs revolutions

a)

b)

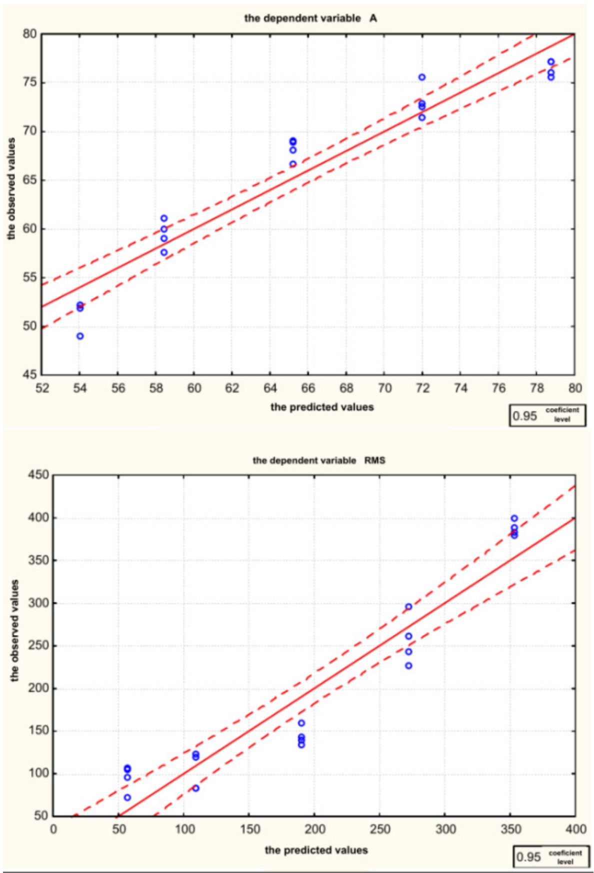

Fig. 8. Plots of the predicted values versus observed values for: a) amplitude, b) RMS

Conducted research studies are preliminary and the authors aim at this stage was to determine the relationship between certain variables and predict the direction of their changes. Undamaged slide bearing is the source of distinguishable acoustic emission signals at different speeds and different bearing load. Moreover, improper parameters of the oil film (occurring at low speed of the shaft) are noticeable by increasing the amplitudes scattering of signal events. The RMS value and the amplitude of the events indicate changes of the bearing rotational speed and thereby changes of the operations parameters. Therefore, there are at least two independent diagnostic parameters.

6. Summary

After the experiment, it can be stated that the acoustic emission can be an effective diagnosis tool of the bearing operating status. Presumably, this method can also be used to diagnose damage of the bearings, as well as to identify them. In the future, the authors plan to conduct research of the bearing damage impact on the parameters of acoustic emission. It is planned to provide a database comprising types of defects and the corresponding change in the acoustic emission signals for the long bearings, i.e., those where the bearing length is greater than its diameter. It is also intended to extend a database for short bearings, i.e., those whose width is close to the diameter. The authors are interested in the ability to identify marine bearings damages with the help of autonomous system equipped with elements of artificial intelligence.

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