Contactless Diagnostics of Turbine Blade Vibration and Damage

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Abstract. The study deals with the contactless diagnostic method used for the identification of steam turbine blade strain, vibration and damage. The tip-timing method based on the evaluation of time differences of blade passages in different rotor revolutions has been modified and improved to provide more precise and reliable results. A new approach to the analysis of the amplitude and time differences of impulse signals generated by a blade passage has been applied. Amplitudes and frequencies of vibrations and static position of blades ascertained by the diagnostic process are used to establish the state of blade damage. A contactless diagnostic system VDS-UT based on magneto-resistive sensors was developed in the Institute of Thermomechanics Academy of Sciences of the Czech Republic. The system provides on-line monitoring of vibration amplitudes and frequencies of all blades and notification of possible blade damage. Evaluation of the axial and circumferential components of the deflections by measuring the amplitude of blade impulse signals results in an overall improvement of the method. Using magneto-resistant sensors, blade elongation and untwisting can be determined as well.

1. Introduction
Damage of steam turbine blades has always resulted in great economic losses. It is very expensive to open a turbine, dismount casing and stationary blades, remove rotors and replace damaged blades. The effort is to install diagnostic systems and operate turbines, so that early detection of blade damage would prevent extensive accidents. One possible solution is to use a telemetric strain-gauge system. The strain gauges are attached at reference points of selected blades. Frequencies and amplitudes of blade vibrations are ascertained by means of measurement of strain dynamic components. Position of blades, which can yield significant diagnostic information on blade damage, cannot be measured by strain-gauge systems. Another disadvantage is the short lifetime of strain gauges in the aggressive environment of the steam turbine, usually of several days or weeks. Only some selected blades can be monitored by these systems.

Contactless systems with stator sensors enable monitoring of all blades of the stage. The diagnostic system (VDS-UT) was developed in the Institute of Thermomechanics of the Academy of Sciences of the Czech Republic. Design and construction of this system are based on previous versions of measuring systems elaborated in the Institute for investigation of static and dynamic characteristics of blade vibration of low-pressure stages of steam turbines. The basic method of these systems is the so-called tip-timing method, utilizing time-differences comparison of passages of single blades along position sensors in different rotor revolutions. The contactless position sensors are usually located
uniformly along the circumference of a turbine stator. Static characteristics, amplitudes and frequencies of blade vibration are determined as a result of a relatively complex calculation procedure. Observing trends of relative blade distances, blade cracks can be early diagnosed. An estimate of blade operational strain and damage can be performed on the basis of the analysis of circumferential components of blade vibration amplitudes.

## 2. Contactless Methods for Blade Damage Assessment in Steam Turbines under Operation

Monitoring of dynamic characteristics, i.e. amplitudes and frequencies of vibrations, represents a fundamental contactless method for damage assessment of turbine blades under operation [1]-[6]. These methods are based on the fact that dynamic characteristics of a blade change as a result of creation and progress of a crack at the blade root. Increase of vibration amplitude and a frequency shift by up to 3 Hz is expected in case of a more significant crack of 10% blade root cross-section.

However, operational measurements at 1000 MW turbine confirmed only amplitude increase of vibrations of the blades on which cracks have later been identified. A possible reason of this could be that measurements were carried out on already damaged blades. However, another cause of this phenomenon can be based on the excitation of forced blade vibrations, which is proved by the fact that blades vibrate at one frequency. The authors have therefore suggested a new contactless method for damage assessment of turbine blades under operation, which is presented in this study. Assessment of blade damage was based on the assumption that the presence of cracks would lead to changes of position between adjacent blades. The situation is depicted in Fig. 1. As a result of a change in mechanical properties the blade BL2 is deflected in the axial direction by \( d_x \). The axial position of the blade can be measured directly by a sensor operating on a magnetic principle. However, the sensitivity of a magnetic sensor is not sufficient to distinguish displacement of the order 1 µm. For example, the sensitivity of the magneto-resistive sensor is approx. 1mV/mm. Signal noise does not enable to measure directly in the µV range. More convenient is to measure the axial deflection indirectly as a time difference in the radial direction. The measurement of time is realized with great accuracy and resolution.

The axial deflection \( d_x \) appears as a radial shift \( d_y \). The deflected blade BL2 approaches the foregoing blade BL1 (see Fig. 1). Originally uniform spacing of the blades \( d_i \) is converted into two different distances

\[
d_2 = d_i + d_y, \quad d_3 = d_i - d_y .
\]

The axial deflection \( d_x \) can be expressed by means of the radial deflection \( d_y \) and the angle of the blade \( \alpha \) as

\[
d_x = d_y \cdot \tan \alpha = \omega R \cdot \tan \alpha \cdot dt = 2\pi f \cdot \tan \alpha \cdot dt ,
\]

![Figure 1. The deflection of a damaged blade.](image)
ω is the angle frequency and \( f \) is the frequency of rotation, \( R \) is the diameter to the blade tips, \( dr \) is the time difference of the blade passage along the sensor S1 created by the radial shift \( dy \). The untwisting \( d\alpha \) of the blade BL2 can be neglected. At the turbine operational speed \( f \) is equal to 50 Hz. Supposing \( \alpha = 20^\circ \), the equation (2) gives \( dx = 114.35 \, dt \). The time of blade passage along the sensor S1 can be measured with the resolution of \( 10^{-8} \, \text{sec} \). That enables to distinguish an axial blade deflection of the order of 1 \( \mu \)m. The resolution of the axial deflection can be improved by a statistical data processing. The statistical data processing of large data files is necessary for elimination of blade vibration. An important indicator is the trend in the diagnostic quantity. One mean value for 24 hours seems to be sufficient information for monitoring the development of blade axial displacements. The number of sensors in the measuring system can be greater than one. The average 24 hours’ value in the system with one sensor can be calculated from approx. \( 1.10^6 \) readouts.

An example of a long-term drift of blade distances during the period of 245 days is shown in Fig. 2 (measured at the power plant Temelín, stage L-1). The differences of the distances from the average value in mm of the blade BL56 (abbreviated designation of the blade No. 56) and the adjacent blades BL55, BL57, BL58 were obtained by means of time-difference measurements with a resolution of 10 ns. The distance shift in the vicinity of the 150th day occurred after turbine shutdown. The blade BL56 was characterized by higher vibration amplitudes. A microscopic fatigue crack has been identified in the root of this blade after the period shown in Fig 2.

![Figure 2. An example of a long-term drift of blade distances during the period of 245 days.](image)

The initial values of blade distances are ascertained immediately after the turbine start-up. The diagnostic system provides monitoring of the circumferential distances of the blades on the basis of a precise time measurement. The trends of recorded values are evaluated. A systematic trend of a blade distance shift indicates the possibility of a blade crack. It is recommendable to observe the amplitudes and frequencies of blade vibration at the same time. On the basis of this complex information it is possible to derive conclusions about the damage of blades. If a blade had a trend of steadily increasing values of axial displacement by large vibration amplitudes, there is a high likelihood of developing fatigue cracks.
Contactless systems of previous concepts are designed to measure a static deflection and bending vibrations of blades. These systems can be extended to measure the blade untwisting and torsional oscillations, as well. For this purpose, two sensors are placed on the stator against the blade tips so that one sensor is located near the leading and the other near the trailing edge of the blade (sensors S2, S3 in Fig.1). The axial displacement of these sensors $d_{xS}$ is equal to the width of the track of the blades. The circumferential distance of both sensors $d_{yS}$ equals to the projection of the blade tip into the circumferential direction. This condition is usually difficult to meet with sensors working on magnetic principle. The sensor must have a minimum distance not to interact with each other. Correction to the actual circumferential distance of the sensors can be made in the subsequent calculation.

It is necessary to determine the initial angle $\alpha_{0k}$ of the $k$-th blade to the plane of rotation for the calculation of a blade untwisting. This angle is either known by design or has to be measured at rest from dimensions or measured under a slow rotational speed $rpm_0$ as an average from $n_j$ rotations

$$\alpha_{0k} = \frac{1}{n_j} \sum_{j} \arctg \frac{dx_S}{dy_S} \frac{dx}{2\pi \ rpm_0 R (t_{2jk} - t_{1jk})} .$$

(3)

$R$ is the radius to the blade tips, $t_{2jk} - t_{1jk}$ is a time difference of the passage of the $k$-th blade in the $j$-th revolution along the sensors S1 and S2. The untwisting of the $k$-th blade $d\alpha_k$ by the operational speed $rpm$ is defined as the difference from the initial angle of the blade

$$d\alpha_k = \frac{1}{n_j} \sum_{j} \{ \alpha_{jk} \} = \frac{1}{n_j} \sum_{j} \{ \arctg \frac{dx}{2\pi \ rpm R (t_{2jk} - t_{1jk})} \} = \alpha_{0k} .$$

(4)

Subtracting the mean value of the untwisting of the $k$-th blade (4) from the sequence of instantaneous values $\alpha_{jk}$ in all revolutions, we obtain a sequence characterizing the dynamic component of the blade untwisting. The amplitudes and frequencies of the torsional vibration of all blades can be subsequently ascertained from these data by means of the frequency analysis DFT.

The value of blade untwisting can be used for a blade damage operational diagnostics as it is suggested in Fig.1. This assumption has not been verified yet. Results of calculations show that an angular deflection by a crack of 10% blade cross-section would not exceed $0.1^\circ$. This value is on the threshold of resolution of this method. Measurement of axial displacements by means of time differences of blade passages gives better sensitivity and accuracy.

The contactless method can be applied for the measurement of the clearance and blade elongation due to the centrifugal force [7]. Advantageous for this purpose are magneto-resistive sensors, the characteristics of which do not depend on the relative speed of the blades to the sensors and thus on the speed of the turbine. The amplitude of the output impulse of the magneto-resistive sensor is evaluated instead of the instant of the impulse slope. A blade elongation and clearance are calculated from the calibration curve of the MR sensor (Fig.5). Using one sensor, elongation of a central point of a blade can be determined. To measure blade elongation at the leading and trailing edges separately, two sensors have to be used like S2, S3 in Fig.1. The values of elongation calculated from the data of these sensors are not identical due to a different blade thickness at the leading and trailing edge.

An initial distance of single blades from the stator sensors is established during a low turbine speed as a sequence of values $z_{0ik}$, where $i = 1, 2, \ldots, n_s$ is the number of a sensor, $k = 1,2,\ldots, m$ is the number of a blade. These values are calculated from the calibration curve of the magneto-resistive sensor as an average from measurements in $n_j$ revolutions

$$z_{0ik} = \frac{1}{n_j} \sum_{j} \frac{z_{ijk}}{n_j} .$$

(5)
The same measurements are made at the full operating speed. A blade elongation is calculated as the difference of the blade tip radial distance from the original position. The measured data include radial bending deflections of the rotor that can be eliminated by averaging readouts of more sensors placed on the stator. The elongation $d_{lk}$ of the $k$-th blade is given as the mean value of distance differences of all sensors

$$d_{lk} = \frac{1}{n_k} \sum_{i=1}^{n_k} \left( \frac{1}{n_j} \sum_{j=1}^{n_j} z_{ijk} - z_{0jk} \right), k = 1,2,\ldots, m.$$  

(6)

Blade elongation is a very important characteristic of a turbine operation. The authors are not aware of an earlier operational method that would allow a measurement of this quantity. However, use of this method for blade damage assessment is also limited by an accuracy and reproducibility of measurements of output voltage amplitudes of magneto-resistive sensors.

3. Diagnostic System of Static and Dynamic Characteristics of Turbine Blades

The system is based on the method, which is referred to as a time-difference or tip-timing method. The principle of this method lies in the precise measurement of time of blade passages along contactless sensors placed on the turbine stator and evaluation of blade vibrations from variations of time data obtained in a section of subsequent revolutions [8]-[12]. The principle of this contactless diagnostic system can be seen from the block diagram in Fig.3. The contactless sensors S1, S2, S3, ... placed around the stator generate impulse signals by passages of each turbine blade tip. The sensor S0 detects passages of a magnetic reference mark attached to the turbine rotor shaft.

Impulse output signals from the sensors are shaped and digitized in the Signal-Processing Unit (SPU). This unit has to be located in the vicinity of the turbine casing to minimize a distortion of the impulse signals. This unit includes a precise counter and, as the result, a numerical value of time is assigned to each generated pulse. The time data complemented by a sensor address and auxiliary operational readouts are sent to a local or distant Data-Processing Unit (DPU). The time differences of each blade passage are calculated and transferred to circumferential deflections and subsequently to blade bending deflections. Using the algorithm of DFT, the amplitudes and frequencies of vibration of all blades can be ascertained.

The tip-timing method is based on a precise measurement of time values $t_{ijk}$ with a necessary resolution of up to 10 nsec, when the $k$-th blade ($k = 1, 2, \ldots, n_B$) passes in the $j$-th revolution along the sensor $Si$ ($i = 1, 2, \ldots, n_S$). The data acquisition process takes $m$ revolutions ($j = 1, 2, \ldots, m$). We can express the differences of the time values $t_{ijk}$ related to the time reference $t_{0jk}$ for the $k$-th blade in the $j$-th revolution as a vector

$$\{dt_{1jk} = t_{1jk} - t_{0jk}, dt_{2jk} = t_{2jk} - t_{0jk}, \ldots, dt_{nSjk} = t_{nSjk} - t_{0jk}\}$$  

(7)

Selecting subsequently proper elements from all $m$ vectors (7), we obtain a sequence of time differences describing the behaviour of a $k$-th blade after a permutation

$$D_k = \{dt_{1jk}, dt_{2jk}, \ldots, dt_{nSjk}, \ldots, dt_{2jk}, \ldots, dt_{nSjk}, \ldots, dt_{nSmk}\}.$$  

(8)

The sequence of time differences in (8) can be transferred to the sequence of deflections of the $k$-th blade in the circumferential direction

$$Y_k = 2\pi f_r R D_k, \quad k = 1,2,\ldots, m,$$  

(9)

where $f_r = rpm/60$ is the rotational frequency of the bladed wheel and $R$ is the radius of the blade tips. Assuming that the circumferential deflections are caused exclusively by a blade bending, the sequence of samples describing the bending movement of the blade can be expressed as

$$V_k = Y_k \sin \alpha = \{v_1, v_2, \ldots, v_N\}_k, \quad N = m \cdot n_S, k = 1,2,\ldots, m.$$  

(10)
Figure 3. Block diagram of the contactless diagnostic system.

\( \alpha \) is the blade angle to the circumferential direction, \( N \) is the total number of samples of the sequence of the bending deflections \( v_i \). Frequency analysis of the bending vibration of the \( k \)-th blade is performed by the discrete Fourier transform (DFT)

\[
X_k = \sum_{n=0}^{N-1} v_n \exp\left(-\frac{2 \pi i}{N} ln\right) = \mathcal{F}\left(V_k\right), \quad l = 0,1,\ldots, N-1.
\]

(11)

Writing \( X_i \) in polar form, we immediately obtain the amplitude and phase spectrum

\[
A_k = |X_i|, \quad \phi_k = \arg(X_i),
\]

(12)

respectively. The calculation of the amplitude spectrum is usually followed by a procedure of selecting and arranging the spectral components in order of their priority.

Estimation of the value of strain at the root of a blade corresponding to a determined bending deflection is performed on the basis of either a previous static calibration or a simultaneous operational tensometric measurement. The static calibration can be realized by a simultaneous measurement of tip deflections and strain at the root of a fixed blade. Resonant vibration of the blade has to be excited by a heavy-duty vibrator or a power electromagnet. Measurement of blade tip deflections can be advantageously realized by a laser vibrometer; corresponding strain in different locations of the blade root can be ascertained by a strain gauge system. More precise values are provided by an operational calibration, which demands the embedding of a radiotelemetric system into the turbine and is consequently more expensive. The error of the static calibration ranges from 10 to 20\%, whereas the error of the operational calibration is less than 5\%. It can be written

\[
\sigma(t) = Q[v(t)] \quad \text{or} \quad v(t) = Q^{-1}[\sigma(t)].
\]

(13)

where \( Q \) represents the operator of the calibration process and \( \sigma(t) \) and \( v(t) \) designate the bending strain and a tip deflection in time domain respectively.

For example, for the 590 mm blade used at the power plant Temelín, the values of \( Q = 11.8 \) MPa/mm and \( Q = 114 \) MPa/mm were ascertained for the first mode of vibration (170 Hz) and for the second mode of vibration (280 Hz), respectively.

The described system is capable of operation in various alternatives. The simplest version involves one reference sensor (S0) and one stator sensor (S1). This system has been in operation at the power plant Prunéřov II since 2005. However, the simplicity of this configuration induces several
disadvantages. A low sampling rate (50 Hz at 3000 rpm) and a consequently narrow frequency band of the DFT (25 Hz) are the most substantial sources of errors. Moreover, rotor speed instability and torsion vibrations of the shaft cannot be eliminated in the case of this simple system.

Increasing the number of stator sensors, the frequency band of the diagnostic system expands correspondingly. For example, the system with eight stator sensors features the frequency band of the DFT of 200 Hz, which appears to be sufficient for most practical applications. A further step to improve the contactless diagnostic system is to increase the number of reference marks on the rotor. A sufficient number of rotor marks enables the elimination of rotor speed changes and torsion vibrations of the shaft mentioned earlier. Using more radial reference sensors, or involving an axial reference sensor in the system, enables the achievement of a more precise elimination of interfering motions of the rotor. In the diagnostic system developed in the Institute of Thermomechanics for the power plant Temelín, eight stator sensors, two radial reference sensors, eight reference rotor marks and one axial reference sensor detecting the passages of holes under blade roots were used.

An example of the results of evaluating computations by the diagnostic system VDS-UT can be seen in Fig. 4. A time course is shown of the maximal amplitude $A_{\text{max}}$ of vibrations in $\mu$sec (lower curve) of the low-pressure-stage blade BL56 compared with the course of power (upper curve) of a steam turbine at Temelín. Turbine output is given in percentage. We can observe a growth of vibration of the blade during the increase of power. Two regions of excessive vibrations occur in the selected period. However, a direct relation between the amplitude of blade vibration and the value of turbine power has not been proved. Excessive blade vibration has always been observed after a rapid change in power. Under the turbine operation the group of blades BL51-BL56 was identified by the diagnostic system VDS-UT, which had increased amplitudes of vibration on the 1st bending eigenfrequency. The increased amplitudes were detected during a one-year’s period especially by starting-up phases of the turbine. On the other hand, no frequency shift was observed during this operational period. After the turbine shutdown, hairline cracks were identified at the blades BL51-BL56 by a magnetic screening method.

![Figure 4. The course of the maximal amplitude $A_{\text{max}}$ [μs] of time differences of a low-pressure-stage blade BL56 compared with the steam-turbine power P [%].](image)
4. Magneto-resistive Sensors

Generally, optical, induction and capacity pick-ups can be used for the contactless sensing of an instantaneous position of moving machine parts. An essential improvement of the diagnostic system has been accomplished by using sensors based on the magneto-resistive (MR) principle which have been developed for this purpose in the Institute of Thermomechanics [13], [14]. These sensors have not only brought higher accuracy and better dynamic characteristics of the sensing process, but have also promoted the introduction of new diagnostic methods as mentioned earlier.

MR sensors consist of a magneto-resistive pick-up and either an internal or external source of a magnetic field. These sensors permit sensing of rapid changes of the magnetic field with a frequency range of up to 10 MHz and thus feature a wide measuring range of velocity from 0 m/sec up to 700 m/sec at a distance of the sensor from a moving blade up to 10 mm. A temperature range of up to 200°C by 100% humidity can be achieved by a suitable construction of the sensors, including resistance to erosion caused by water drops.

A necessary condition for the use of MR sensors is that the blades are made of a magnetic material. The source of the magnetic field can be formed directly by the magnetized blades. Using an internal source of magnetic field located inside the sensor, e.g. permanent magnets, forms a more convenient version with a higher stability of the magnetic field. In this case, however, the blades should be thoroughly demagnetized.

A movement of a blade tip in the magnetic field of the permanent magnet has the consequence of a change in the direction and distribution of the magnetic field lines, which induces a change in the electrical resistance of the MR pick-up. Used magneto-resistors of the brand Philips are based on the magneto-resistive phenomena of a thin layer of the magnetic material Permalloy. The dependence of the resistance $R$ of the pick-up on the angle $\beta$ of the intensity of the resulting magnetic field has an anisotropic character

$$R = R_0 + \Delta R \cos^2 \beta,$$

(14)

$R_0$ is the resistance of the magneto-resistive element at the intensity of the magnetic field $H=0$; $\Delta R=(R_{\text{max}} - R_{\text{min}})/2$; $R_{\text{max}}$ is the resistance $R$ by $\beta = 0$; $R_{\text{min}}$ is the resistance $R$ by $\beta=90^\circ$. Produced pick-ups have layers of Permalloy coated by skew aluminium stripe layers with the result in a shifted current direction in the layer by $\pm 45^\circ$, which enables the creation of an active bridge of these elements. The advantages of this arrangement are a quadruple increase in sensitivity, compensation of temperature dependence of the sensor, and a particularly common-mode signal rejection, which is important, especially in operational conditions.

Subsequently, as follows from expression (14), the output bridge voltage of the magneto-resistive sensor $U_S$ is a function of the intensity and direction of the magnetic field and it can be written as

$$U_S = c_S U_N H_{S0} \sin 2\beta,$$

(15)

c_S [m/A] is the sensitivity of the sensor; $H_{S0}$ [A/m] is the value of the resulting intensity $H_S$ of the vector of the magnetic field to which the sensor is exposed by $\gamma=0$; $\beta$ is the angle between the axis $z$ and the direction of $H_S$. Using the supply of the bridge with a constant current $I$, the temperature dependence of the sensitivity $c_s$ can be reduced to approximately four times less, and the supply diagonal voltage drop can be used for the measurement of the internal temperature of the sensor.

The behaviour of an MR sensor and the level of an output voltage at the sensor bridge during a blade passage with a circumferential velocity ($c=\omega R$) can be seen in Fig.5. The adjacent graph in Fig.5 shows the measured dependence of the peak-to-peak value of the output sensor voltage ($U_{S_{\text{p-p}}}$) at a distance $z$ between the sensor and the tip of the 590 mm blade. A necessary requirement for the symmetry of the negative and positive pulses generated by a blade passage and the equality of amplitudes ($|U_{S_{\text{max}}}|=|U_{S_{\text{min}}}|$) is the symmetry of the orientation of the magneto-resistive pick-up in the direction $y$. 

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Figure 5. The response of the output voltage of a magneto-resistive bridge on a blade tip passage; the dependence of the peak-to-peak output voltage on a distance $z$ between the sensor and a blade.

The results from measurements of static characteristics of the same sensor No.1 are presented in Fig.6. The data were obtained by measurements on the precise positioning desk. As can be seen, the amplitudes of the generated pulses are dependent on the distance $z$ between the sensor and the blade. A very important factor for the method of time differences is that all curves go through the zero voltage level in the same time instant. In other words, the time of the passage of the output voltage of the sensor through the zero level is independent on a radial blade distance, and measurements of circumferential blade deflections can be performed on the basis of precise time measurement.

Figure 6. Static characteristics of the MR sensor No.1: Output voltage in dependence on a circumferential distance $y$ and a radial distance $z$ between the sensor and the 590 mm blade.

Dynamic characteristics of the developed MR sensors have been tested on the experimental bladed wheel at the Institute of Thermomechanics. Special testing equipment has been developed to establish the accuracy of the MR sensors. An impulse magnetic field with a frequency from 0 to 10 kHz was generated to simulate passages of the blades along the tested sensor. Both rising and falling edges of the sensor output signal were below 0.1 µsec. The typical delay of the signal was 1 µsec with reproducibility better than 10 nsec. On the basis of static and dynamic tests a new type of MR sensor has been developed and used in the diagnostic system (VDS-UT) operating at the power plants Pruněřov II and Temelín.
5. Conclusion

Several diagnostic methods for damage assessment of steam turbine blades under operation have been suggested. These methods can be divided into two classes as static and dynamic. Static methods, newly introduced by the authors of this paper, are based on contactless measurements of blade position and evaluation of its shift from the original position. The method of trend monitoring of the axial blade deflections features a highest sensitivity and accuracy. Even at supersonic tip speeds up to 700 m/sec, deflections of 0.01 mm can be reliably distinguished. The distinction between blade position drift and a systematic position change of blades due to a crack development makes main limitation of this approach. Long-term trends of blade position with changes exceeding 0.1 mm have to be monitored for an effective blade damage assessment. The static method has been applied and verified for an operational blade damage assessment at the power plant Temelín.

Dynamic methods, known as tip-timing, are based on measurements and frequency analysis of blade vibrations. The contactless diagnostic methods have been improved in the Institute of Thermomechanics, which resulted in the utilization of the contactless system VDS-UT at power plants in the Czech Republic. Operational measurements on the 1000 MW turbine at the power plant Temelín confirmed an increase in vibration amplitudes of the blades on which cracks have later been identified. The dynamic method has been applied and verified at Temelín as well. The frequencies of blade vibrations during an annual period remained unchanged, which appears to be a limitation of this approach.

New magneto-resistive sensors of the Institute of Thermomechanics have induced further development of the contactless diagnostic methods. These sensors feature a wide operational velocity range of blade tips in the range from 0 m/sec to 700 m/sec with a constant amplitude of the output voltage. The original tip-timing method based on the precise measurements of time differences has been extended by the method of amplitude differences. This method enables us to measure not only vibration and stress of particular blades, but also orbits of the bladed turbine wheel and components of the shaft movements.

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