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TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

113

Selected papers from the International Conference on *Turbines of Large Output* devoted to 100th Anniversary of Prof. Robert Szewalski Birthday, Gdańsk, September 22-24, 2003

WYDAWNICTWO IMP PAN

GDAŃSK 2003

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

Appears since 1960

Aims and Scope

Transactions of the Institute of Fluid-Flow Machinery have primarily been established to publish papers from four disciplines represented at the Institute of Fluid-Flow Machinery of Polish Academy of Sciences, such as:

- Liquid flows in hydraulic machinery including exploitation problems,
- Gas and liquid flows with heat transport, particularly two-phase flows,
- Various aspects of development of plasma and laser engineering,
- Solid mechanics, machine mechanics including exploitation problems.

The periodical, where originally were published papers describing the research conducted at the Institute, has now appeared to be the place for publication of works by authors both from Poland and abroad. A traditional scope of topics has been preserved.

Only original and written in English works are published, which represent both theoretical and applied sciences. All papers are reviewed by two independent referees.

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TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 113, 2003, 3-4

Editorial

These Special Issues of the *Transactions of Fluid-Flow Machinery*, Nos. 113 and 114 contain selected papers from the International Conference on *Turbines of Large Output* devoted to commemorate 100$^{\text{th}}$ Birthday Anniversary of Prof. Robert Szewalski. The conference was held in Gdańsk, Poland on September 22-24, 2003.

The Conference is a continuation of previous conferences held at the Institute of Fluid-Flow Machinery PAS in former years dedicated to technology of steam turbines. Series of conferences bearing the same name took place in the years 1962, 1965, 1968, 1993. In 1997 organised has been a conference on steam turbines and related topics, but with a slightly amended title – *Problems of Fluid-Flow Machinery.* At present at the Institute of Fluid Flow Machinery there are conduced research of fundamental character encompassing both the issues related to steam turbines and fundamentals of power engineering.

Organisers of the present conference have returned to the traditional name, i.e. Conference on *Turbines of Large Output* to mark the respect to the memory of Professor Robert Szewalski (1903-1993), the founder and a director of the Institute of Fluid-Flow Machinery for several years, and initiator of the conference series devoted to the problems of steam turbines.

The Editors are very grateful to the referees of the papers presented in this issue of the *Transactions of Fluid-Flow Machinery*: J. Badur, W. Batko, E. S. Burka, J.T. Cieśliński, P. Doerffer, A. Gardzilewicz, B. Grochal, J. Kiciński, G. Kosman, T. Król, J. Krzyżanowski, J. Mikielewicz, A. Neyman, W. Ostachowicz, R. Puzyrewski, R Rządkowski, J. Świrydczuk, M. Trela, T. Uhl and Z. Walczyk.

We appreciate cordially the manifested authors interest in our conference. Special thanks are conveyed to Ms 'Maya' Bagińska, for her fruitful editorial help related to directing the papers to reviewers and correspondence with the authors of contributions.

Prof. Jarosław Mikielewicz
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TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 113, 2003, 129-136

EDWARD DZIĘCIOŁ* and ANDRZEJ SZCZEPANKOWSKI

Microwave detector as used to monitor health/maintenance status of aircraft engine's turbine blades in hot gas

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Abstract

The paper has been intended to present some selected issues of taking measurements of rotating components under extreme operating conditions, in particular at high temperature. Tests have been suggested with microwave detector of motion applied, one that co-operates with systems using both the homodyne detection of a high-frequency signal and the frequency-based measurement of time intervals. Fundamental technical problems of the method while taking measurements on a real object have also been indicated.

Keywords: Microwave motion detector; Homodyne detection; Turbine

1 Introduction

Diagnostics of health/maintenance status of rotating blades of turbine aircraft engines is performed solely in the course of manufacturing and repair/overhaul processes. Flow detection methods and fatigue testing of some representative number of samples are used to identify health/maintenance status of the blades. The knowledge gained is usually used to determine the time horizon of further safe operation of the engine [5]. However, as the fleet has been ageing, the monitoring/inspection methods in use up to the present have become insufficient. Therefore, a need arises to develop a complex method of monitoring the turbine blades' health/maintenance status. The efforts to undertake such work have

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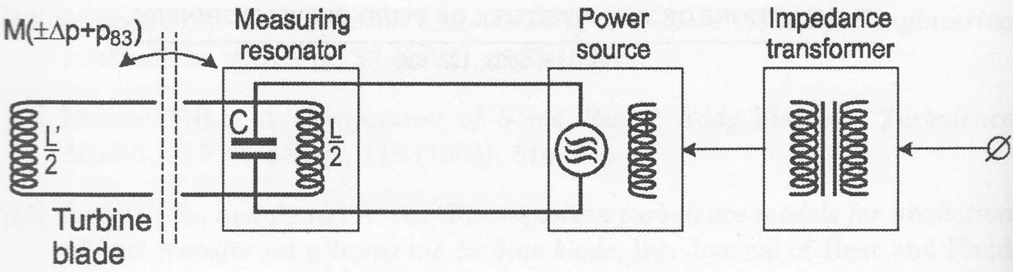

Figure 1. Functional diagram of the arrangement of the microwave motion detector's antenna (L – inductivity of the resonant circuit, L' – inductivity representing the turbine rotor blade, $\pm\Delta\varphi$ – useful signal, p – blade-rim pitch).

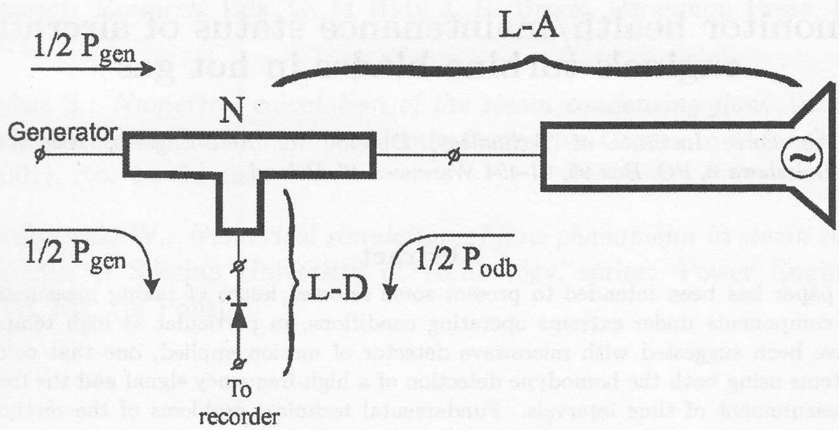

Figure 2. Functional diagram of the homodyne – detection arrangement of the microwave motion detector (L-D – peak-detector-subsystem line, L-A – antenna-subsystem's line, P_{gen} – power of the generated continuous wave, P_{odb} - power of the reflected wave).

been made in Poland due to three instances of fatigue breakaway of chrome-coated blades of turbines of aircraft engines of the SO-3 type. The work has been initiated by the WSK „PZL-Rzeszów" S.A. (Means of Transport Manufacturing Company, Inc.) and ITWL (Air Force Institute of Technology). Studies performed till now comprised examination of the suitability of already designed measuring systems with inductive, eddy-current and capacity detectors engaged. The disadvantageous test results were obtained, due to:

- steady state of the engine – unsatisfactory signal-to-noise ratio,
- acceleration – signal fading due to high temperature and ionisation of exhaust gas flowing through the turbine.

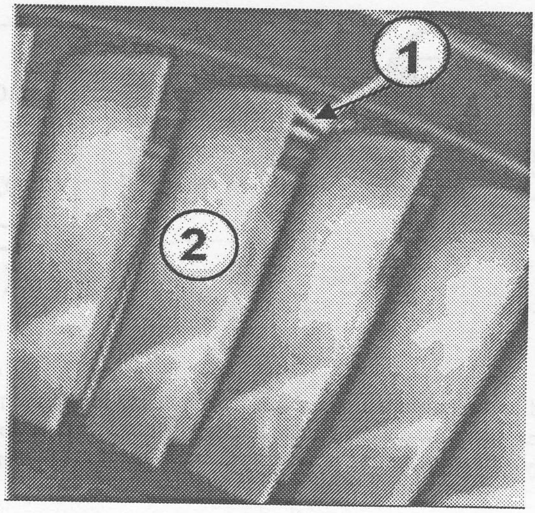

Figure 3. The face area of the motion detector upon the turbine rotor blade tips (1 – detector – microwave antenna, 2 – turbine-rotor blading).

This induced the Authors to check whether measurements of vibration of rotating blades with the microwave motion detector are feasible at all.

2 The course and results of studies/tests

Evaluation of the feasibility of applying the microwave motion detector to examine vibration of turbine blades has been performed in two stages [2, 4]:

- while designing the microwave detector, and
- during stand tests of the measuring line on the engine of the SO-3 type.

2.1 Preparations to tests

The designed microwave motion detector has been accommodated to very special conditions of turbine blades operation, in particular, to high temperature. A microwave antenna has been used as a motion detector [1, 3], see Figs. 1 and 4. The subassemblies thereof have been air-tight sealed with dielectric body within a common case. The motion detector comprises several subassemblies: a microwave continuous-wave generator, an antenna, and a homodyne detector – Fig. 2. In the construction of the detector a 'two-way' system with the magic 'T' of the 'N' type has been used with analytically determined and laboratory verified lengths of arms L-A (antenna subassembly) and L-D (homodyne peak

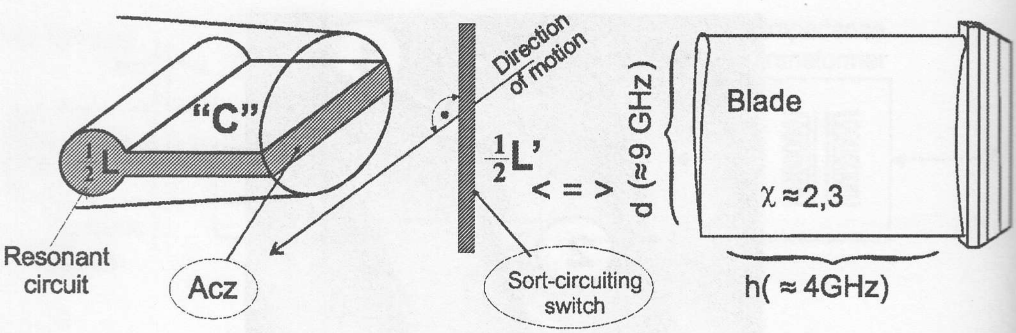

Figure 4. The blade-effected inductive closure of the capacity-inductive resonator of the motion detector (Acz – microwave detector's antenna, L – inductivity of the resonator's cavity, C – capacity of the resonant circuit, L' – inductivity representing the turbine rotor blade).

detector subassembly). Transmission, visualisation and recording subsystems are also the components of the measuring system.

In the course of building the detector into the turbine's body, the resonant circuit's opening (aperture) was orientated perpendicular to the blade-tips' chord – Fig. 3.

The symmetry axis of the microwave antenna has been orientated perpendicular to the theoretical axis of rotation of the system under examination.

The selected location of the antenna – directly upon the centres of the turbine-rotor blade tips – has been effected by both the assumed objectives of the measurements and algorithms of signal processing accepted for the discrete phase-mapping method [2, 4].

2.2 Principle of operation of the microwave motion detector's measuring system

As it follows from Fig. 2, some of the continuous-wave power generated in the microwave generator is transferred through one of the arms of the magic 'T' of the 'N' type to the homodyne peak detector, whereas the rest of it is transmitted through the other arm to the antenna. The moment the rotating turbine blade passes by the detector, the 'closure' and the 'opening' of the circuit of the capacity-inductive antenna resonator (aperture) follow in sequence. Following the change in its reflectance (phase shift), some partial microwave signal reflection occurs – Fig. 4. At the antenna input there occurs a phase-modulated signal of power equal to – approximately – half power of a reflected wave. The signal is transferred to the peak detector where it is demodulated and followed with the low-frequency component's separation.

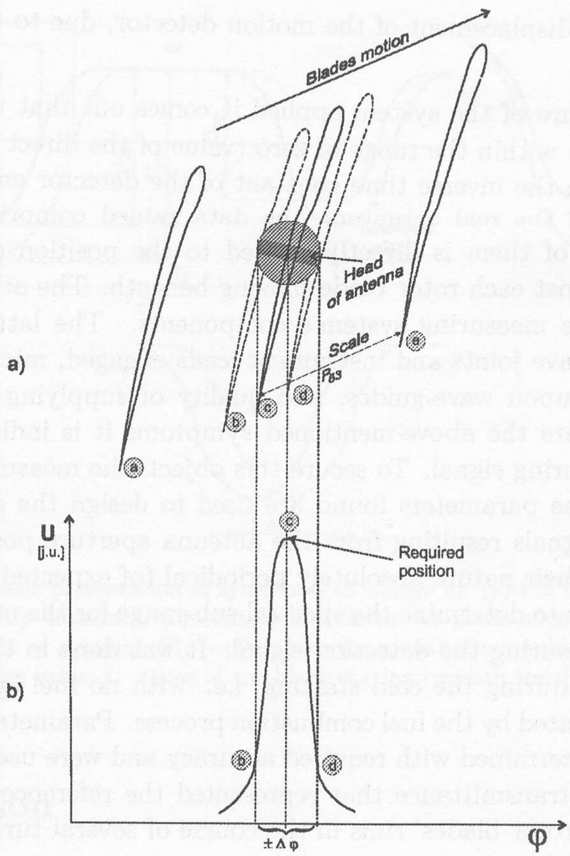

Figure 5. Subsequent stages of forming the signal in the microwave motion detector (U – a unit, by convention, p – blade-rim pitch, φ – angle of rotation of the rotor).

Figure 5 illustrates correlation between the voltage signal and the instantaneous position of the blade tip against the antenna face. The signal amplitude does not, in fact, depend on the rotational speed of the turbine rotor. Owing to this fact, feasible are measurements for the full-range engine speeds, including the engine run-up and slow-down.

3 Measurements handling

The obtained measuring signal contains information on:

- the blade displacement in the rotor planes of vibration (minimum stiffness) and rotational motion,
- the longitudinal displacement of the turbine and vibration thereof,

- the relative displacement of the motion detector, due to the turbine bod vibration.

From the nature of the system applied it comes out that the output sign frequency remains within the range of zero (value of the direct current) throug the value equal to the inverse time constant of the detector engaged. Howeve taking account of the real actuators, the data gained comprise two groups symptoms. One of them is directly related to the position of the microwa antenna face against each rotor blade moving beneath. The other one is relate to the rest of the measuring system's components. The latter is affected b quality of microwave joints and instrument leads engaged, microphonic effect engine vibration upon wave-guides, and quality of supplying subsystems wit power. To separate the above-mentioned symptoms it is indispensable to pr process the measuring signal. To secure this object, the measuring signal has be defined and the parameters found are used to design the optimum spectr filtration. The signals resulting from the antenna aperture position against th blade tip are by their nature absolutely periodical (of expected duration), whic renders possibility to determine the spectral sub-range for the most advantageo conditions of measuring the detection signal. It was done in the course of tes of a real system, during the cold starting, i.e. with no fuel ignition to exclud interference generated by the fuel combustion process. Parameters of the 'spectr mapping' were determined with required accuracy and were used to build a filt showing spectral transmittance that represented the reference signal gained b averaging all the rotor blades' runs in the course of several turbine rotations.

2.4 Test results

On the grounds of the stand tests performed on the SO-3 engine it has bee found that the suggested algorithm of processing a signal from the microw motion detector makes differentiation of diagnostic symptoms feasible – Fig. By way of example, the observed change – by ΔU_{pp} – in the amplitude of volta of the rotating-blade-generated signal, with simultaneously longer time t_i' of th blade's staying beneath the detector proves some change in the blade's angle twist – Fig. 6a. In the case there is only a change in value of the pulse amplitu it is to be recognised that a change in the blade tip clearance has occurre Fig. 6b. If only a phase shift of pulse tip points is to be noticed, the fact h to be attributed to a change of the amplitude of blade vibration in the plane minimum stiffness – Fig. 6c.

The above-presented interpretation refers only to uncorrelated vibrations blades (independent modulators), whereas analysis of the degree of correlatio vibrations of all rotor blades (identification of external modulation) gives groun to identify displacements of the turbine disk and vibration thereof.

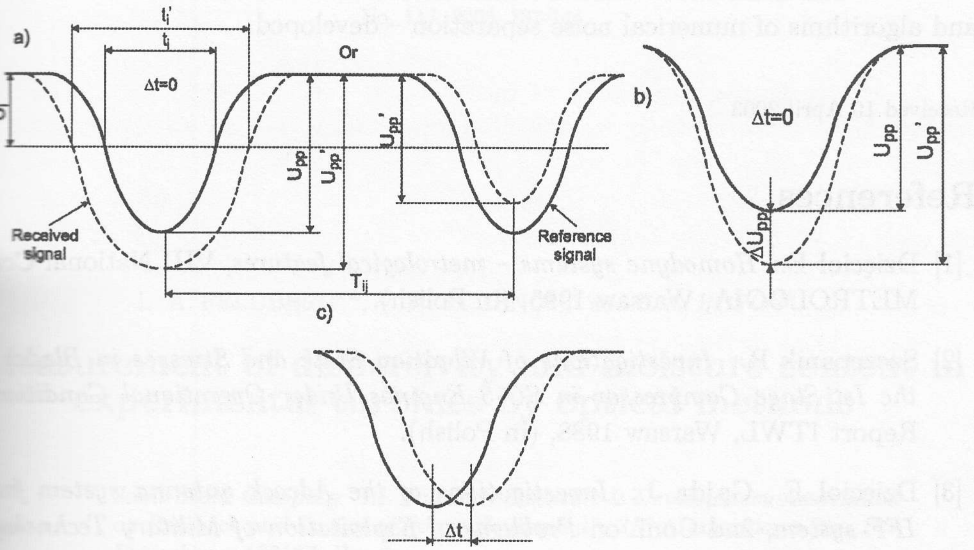

Figure 6. Diagrammatic presentation of symptoms of change in: (a) the blade's angle of twist, (b) blade tip clearance, (c) blade vibration in the plane of minimum stiffness (Δt – time shift of a signal, T_{ij} – pitch between signals from subsequent blades, U_{pp} – peak-voltage value, t_i – time of the blade staying beneath the detector's face).

3 Conclusion

The proposed design solution for the microwave motion detector has facilitated taking some records of vibration of the rotating turbine blades. In spite of the fact that only one detector was used, the obtained signal included information on both the health/maintenance status of the rotating turbine blades and vibro-acoustic processes within the turbine. To extract them, several algorithms have been suggested. These, in turn, facilitate further research and testing work aimed at verification of the hitherto considered prerequisites for fatigue breakaway of the blades.

To practically use the newly developed measuring system it proves indispensable to solve the problem of suppressing the electromechanical noise generated within the microwave lines and affecting the signal. It is, therefore, suggested to redesign the detector in use until now to make it a single compact module. On the other hand, to determine effects of the blade's apparent vibration (the antenna face's getting periodically to and away from the tip area of the blade) it is suggested to simultaneously take measurements with the motion detector and accelerometers built upon the turbine body. Identification of the actual vibro-acoustic phenomena will enable the detector structure to be optimised, and algorithms of numerical noise separation – developed.

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