THE IDEA TO SYNCHRONIZE MEASURING PATHS FOR TWO DIFFERENT CURRENT GENERATORS OPERATED AS POSITION-VOLTAGE CONVERTERS

The study deals with the issue how to apply two different types of current generators at the same time, namely a three-phase AC generator and a DC generator of commutator type. What is more interesting, the two generators would be able to collaborate both during the phase of electromechanical sampling and the phase of electronic sampling. It will enable structural improvement of sensitivity and resolution parameters and shall open new opportunities to investigate new types if mechanical phenomena (that have not been already tracked by means of the FAM-C and FDM-A methods), such as torsion of torque transmission shafts.

Keywords: FAM-C and FDM-A diagnostic methods, synchronization of measuring paths, groove-produced pulsations, monitoring of subassemblies within mechanical driving units, phase configuration, comprehensive measuring system.

1. Introduction

For many years the Air Force Institute of Technology has been applying the FAM-C and FDM-A methods for diagnostics of aircraft driving units [1, 2]. These methods are applicable to Torque Testing Machines (TTM) [5, 12] and consist in indirect measurements of spindle rpm and/or displacement of rotating parts (e.g. compressor blades) and are conventionally carried out by means of electromagnetic, optical, microwave, capacitance or eddy-current sensors [4-6, 12]. In spite of the conventional TTM, the FAM-C [5] method needs to sensor to install since the role of the monitoring device is performed by a typical on-board AC generator. Each pole piece of such a generator acts as a reluctance sensor and tracks displacement paths of rotor grooves. Owing to uniform spacing between pole pieces and the fact that number of such pieces is different than the number of rotor
grooves a specific type of vernier is formed [5, 10]. It substantially improves measurements accuracy for instantaneous rpm and makes it possible to trace fast-changing processes that are theoretically undetectable (for the specific number of grooves or pole pieces).

Each type of current generator features with specific bandwidths of mechanical frequencies [5, 10]. Since maintenance personnel is keen to monitor virtually all mechanical subassemblies the monitoring bandwidth of the measuring system (all incorporated FAM-C and FDM-a measuring channels) should cover all sub-bandwidths produced by individual mechanical subassemblies of the driving system. Such an approach needs to apply a series of measuring devices. But instead of great many measuring systems this study suggests to use only a single one that shall benefit from synchronous compilation (superposition) of electric signals received from several current generators. Advantages of that innovative approach shall be presented on the example disclosed in this paper where combination of two output voltage waveforms from the DC current generator of the GSR-ST-12000WT type and a three-phase current generator was used.

2. General description of operation principle and test devices using the FAM-C method

The FAM-C and FDM-A methods can be applied simultaneously and may complement one another to significantly improve dependability of acquired information and contribute to making the diagnostic results more trustworthy. Owing to synchronization of the process consisting in acquisition of diagnostic information from several current generators (measurement paths) and combined analysis of such data it is possible to investigate many additional phenomena, such as determination of stress level in twisting or torsional members of power or torque transmission mechanisms or wear rates for bearings, in particular when open lubrication system is applied. The presented project substantially expands the scope of investigations related to these topics. The research studies were carried out both as mathematical considerations and practical examination of physical processes [5]. Each measuring path is a source of voltage waveforms of totally different forms (Fig. 1). These differences result for various way how the output voltage is generated:

- AC current generators produce only the quasi-sinusoidal components (with no constant voltage component);
DC current generators of commutator type the first phase of output voltage formation is carried out similarly to the AC machine but the AC current is mechanically rectified by the commutator, which leads to formation of two components: the constant voltage component at the level of 28V DC as well as the variable (AC) voltage component with the rms voltage amplitude from 0.1V to 2.1V. Shape of waveforms for the AC component resembles superposition of two inverted half-sine curves (Fig. 1, detail 2).

Fig. 1. Waveforms produced by two different current generators to be used to measure torsion angle of a transmission shaft: 1 – output voltage from a 3-phase AC current generator (phases A, B and C); 2 – pulsating component for the output voltage produced by a commutator-type DC current generator.

Each of the mentioned current generator needs a different approach to measurements [5] – for a three-phase AC generator the half-period and three-phase counting is applied whilst the commutator-type DC generator employs single-phase full-period counting.

Due to different rated frequencies for each of these current generators also mutually different time base settings are applied:
- for the DC current generators: \( f_{\text{g}} = f_{\text{s}} = 32\text{MHz} \),
- for the three-phase AC current generator \( f_{\text{3-phase}} = f_{\text{s}} = 1\text{MHz} \).
Fig. 2. The way how consecutive transitions through the level of zero voltage are counted up for the three-phase AC current generator: \( u_{AC} \) – voltage waveforms for individual phases of the three-phase generator operated as a position-voltage converter in case of the FAM-C method for consecutive counting intervals (UTTL).

Fig. 3. The way how consecutive transitions through the level of zero voltage are counted up for the commutator-type DC current generator: \( u_{DC} \) – waveform for the pulsating component of the current generator operated as the position-DC current converter in case of the FDM-A method; \( l_1, l_2, l_3, l_4, l_5, l_6 \) – corresponding numbers of pulses for consecutive counting intervals (\( U_{TTL} \)).
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It means that each pulse generated for the FAM-C method corresponds to 32 pulses generated for the FDM-A method. Thus, the total time \( T_{3\text{phase}} \) for generation of a single waveform period of the output voltage by a three-phase AC generator with two-halves measurements (with use of a two-path metering chord and with the time base generator with the frequency \( f_{3\text{-phase}} = f_s = 1 \text{ Mhz} \)) shall amount to:

\[
t_{z1-3\text{phase}} = \sum_{i=1}^{6} k_i \frac{k_i}{1000000} = \sum_{i=1}^{m} k_i \frac{k_i}{f_{z-3\text{phase}}} \text{[s]} \tag{1}
\]

The number of six (6) is implied by the fact that in the measuring system of the SO-3/3W motor every single half-period of a three-phase AC generator comprises six periods of voltage waveforms for the DC component of the AC generator pulsation.

In turn, the time \( T_g \) of a single waveform period (Fig. 3) shall be determined as:

\[
T_{z1g} = \frac{l_i}{32000000} = \frac{l_i}{f_{zg}} \text{[s]} \tag{2}
\]

Thus, the analysis of combined measurements of signals received from the both current generator must employ the rule of coupled ‘families’ \(^1\) [5, 7], with the waveform periods and half-periods are mutually adjusted according to the rule of the Least Common Multiple (LCM). Let us assume that for DC generator it is the value of \( I = \{h, l_2, ... , h, ... , h\} \), whereas for the three-phase AC generator it is the value of \( K = \{k_1, k_2, ... , k_i, ... , k_n\} \). In future the foregoing approach shall be applicable to measurements of the shaft torsion angle down the section between the two generators. It will be possible to continuously monitor dynamic behaviour of the torsion angle for such shafts:

\[
\phi_1 \approx \frac{f_{z3\text{fazmax}} k_1 - f_{zg_{\text{min}}} \sum_{i=1}^{n} l_i}{f_{z3\text{fazmax}} \sum_{i=1}^{6} k_i} \tag{3}
\]

\(^1\) Each ‘family’ is arranged as a set comprising specific number of half-periods for the output voltage waveform of the AC generator and full periods for the output pulsation voltage waveforms of the DC generator.
where: $f_{z-3f_{max}}$ – maximum time base frequency available on metering chords of the measuring system and applicable to the measuring path of the AC generator;

$f_{zg_{min}}$ – minimum time base frequency available on metering chords of the measuring system and applicable to the measuring path of the commutator-type DC generator;

$l_i$ – number of pulses in the consecutive ($i^{th}$) package of pulses over the time interval between adjacent points where the component of commutator pulsation produced by the DC generator intersects the level of zero voltage;

$n$ – number of pulse packages received from the DC measuring path;

$m$ – number of pulse packages received from the AC measuring path;

Comparison between adjacent values of shaft torsion angles makes it possible to determine dynamic behaviour of shaft torsion and make appropriate conclusions. One can also develop necessary mathematic background for other mathematic phenomena, e.g. monitoring of total play in various avionic driving systems and actuators coupled with many other on-board current generators.

3. Recapitualtion and conclusions

The paper discloses an idea how to design a modified and innovative measuring system that benefits from synchronous compilation of signals received from all electric power generators as well as small tachometric generators. Such a solution makes it possible to tremendously expand the monitored bandwidth of various on-board equipment. Actually, according to the suggested solution, only a single measurement system would be able to supervise and monitor all subassemblies incorporated into any avionic driving system that is known by authors of this study. The authors are deeply convinced that synchronization of measuring channels in the manner according to the solution presented in this paper shall enable improvement of the FAM-C and FDM-A methods, increasing their measuring accuracy and make possible to monitor additional mechanical phenomena that has not been traced yet, such as torsion of torque transmission shafts.
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