ABSTRACT

For the last dozen years, ELECTRICITE DE FRANCE has been using a digital telematry system mountable on the rotors of its generating machines in case of acceptance tests or after technical hitch, under difficult environmental conditions (125 degrees C and centrifugal acceleration of 100,000 m/s²). This system, manufactured by SCHLUMBERGER, has proved itself in many test programs on high-power electrical motors, primary pumps of PWR reactors, steam turbines, alternators, etc.

Today, the need is growing towards operational monitoring of equipment.

Using this type of equipment in a monitoring system is a greater challenge. In fact, it is necessary to obtain an MTBF longer than the fuel refilling period (approximately 18 months) to make significant savings in product costs.

A technological upgrade of the existing product was undertaken in late 1989.

A very effective product capable of meeting the needs expressed is now available on the market. The system can be used to build systems with 1 to 63 channels with pass-bands ranging from 250 Hz to 10 kHz and very high precision (approximately 0.1%), under the above-mentioned environmental conditions.

Its size, low power consumption, range of operating temperatures (-20 to 125 degrees C), resolution (12 bits), adaptability and capability of operating under conditions of acceleration and vibrations (100,000 M/s² and 1000 m/s² from 20 to 1000 Hz), make it a unique product of its type.
Although designed for use on rotating machines, these devices, thanks to the designs and technologies used, are compatible with other types of applications.

The central equipment is also modular, a change in the structure of the rotor-mounted system does not call any of the investments into question; only the equipment’s software configuration is modified.

A full line of standard equipment for reception, decommutation, recording and processing is available.

This paper is intended to show how this product was developed so as to meet the main constraints of a system mounted on rotating machines. Problems related to installation on the machine, the power supply to the system and data transmission are not dealt with here. A short video film will illustrate our analysis.

INTRODUCTION

For many years, ELECTRICITE DE FRANCE has been testing its machines to gain knowledge about their operation so as to make better use of them and to dimension new generating plants.

In 1980, ELECTRICITE DE FRANCE asked SCHLUMBERGER Industries to manufacture a digital remote measurement system that can be mounted on machine rotors (electrical motors, pumps, steam turbines, alternators, etc.) in a difficult environment: continuous operation at 125 degrees C and centrifugal acceleration of 100,000 m/s².

This system has proved effective under operation in such varied applications as:

- the study of vibration behavior of the blades of conventional thermal and nuclear low-pressure turbines
- determining the bending and torsion characteristics of the a.c. turbogenerator shaft system
- determining the output of turbo-feed pump sets
- testing the cooling of the 1750 MVA alternator rotor
- endurance tests on primary pump motors (1500 starts/stops).
- etc.

But using this type of equipment in a monitoring system, i.e. over a long period of operation, requires performance levels that are particularly difficult to achieve. The product must be led through two seemingly contradictory stages: improving the degree of reliability (the minimum objective is to guarantee an MTBF greater to the fuel refilling
period of a nuclear set, i.e. approximately 18 months) and significantly reducing equipment costs, with the equipment of some fifty a.c. turbogenerators at stake.

In 1990, ELECTRICITE DE FRANCE and SCHLUMBERGER Industries, to reach the objective, decided to join together to improve the product. A preliminary study of the available technologies showed that a correct choice had been made at the time of initial manufacturing: digitizing in the rotating part prior to transmission and the production of hybrid integrated circuits, which is the technology providing the best MTBF. To improve it, it is necessary to increase the density of integration, minimize the number of interconnections, use a maximum of VLSI components and control the heat dissipation of the components.

It should be pointed out that EDF was already using PCM techniques when the equipment available on the market was (and, in some cases, still is) based on frequency modulation processes, which are inefficient for obtaining high precision with the direct current component and for building multi-channel systems.

In addition, digital techniques greatly facilitate central data processing: storage of the transmitted data, recording with no distortion or loss of precision, direct digital processing (FFT, correlations, etc.).

THE OBJECTIVES

Since the first manufacturing, the technologies and components have been improved a great deal (incidentally, some components are not longer available). To make sure that the product will endure, it would therefore be useful to upgrade the technology and improve certain performance levels, while maintaining compatibility with the old generation. The decision to overhaul the coding and amplifying subassemblies was made in late 1989. At the time, the objectives were: a significant reduction in volume (50%), obtaining an MTBF of 18 months for an amplifying + coding-emission assembly, substantial price reductions for industrial products (at least 20%), doubling the measurement rate (50,000 measurements per second), creating a single channel with a broad pass-band and, finally, researching a new modularity for better adaptation to the latest needs.

It turned out that the modularity chosen previously (a minimal structure of 8 channels) was not always optimal and that it would be desirable, for monitoring alternator rotors, to have a structure of one channel for measuring the rotor current and four channels for the resistance of insulation. These observations, along with the experimental results from the above-mentioned tests, helped to advance development, as we shall see.
RESULTS

All the objectives have been reached and some have even been exceeded, especially in terms of volume, reliability and cost.
Each of the two subassemblies is made from a single large-sized hybrid circuit, reducing their volume from 90 to approximately 35 cm$^3$ (photo 1).
The coding-emission subassembly is the “core” of both the multichannel structure and SINGLE-CHANNEL system with a 10 kHz pass-band. The measurement rate has doubled, amplifier gains are switched via logic levels instead of hard-wire switches.
The MTBF obtained for the coding-emission/amplifying-multiplexing assembly is much greater than expected (40 months instead of 18 months).
The costs savings are twice those expected at the beginning of the study.

Photo 1: Comparison of the two generations (the new one is on the left)
A NEW MODULARITY

The new functional and geometrical modularity makes the system upgradeable and allows for the minimum structure (the coding-emission unit for the rotor-mounted part) to be used as a base for building a modular multichannel system. The central receiving and synchronizing equipment requires software modifications only.

A 35 cm³ module contains the coding-emission unit (remember that it serves as a single-channel system). The same is true of the amplifying-multiplexing unit. It will therefore be possible to create structures ranging from 1 to 63 channels, e.g.: one 10-KHz channel, three 4-KHz channels, four 2-KHz channels, seven 2-KHz channels, fifteen 1-KHz channels, thirty-one 500-Hz channels, sixty-three 250-Hz channels.

The single-channel structure and a few others allow for transparent transmission of a measurement internal to the system (internal temperature or internal voltage) at the same time as the measurements from the sensors; this capability is very useful for operation of the rotor-mounted equipment.

Electrical compatibility with the old generation is ensured. If desired, it is even possible to choose the old measurement rate and to combine generations.

In addition, some potential users have expressed their desire to power the rotor-mounted system via d.c. sources (batteries, storage cells, ring collectors or rotating generators). Such users can now choose the type of power supply. Core transformers distributing rectified currents are now housed in a specific module. The rotating transformer system used on the machines provides power supply and transmission with no contact between the fixed part and rotating part. In this case, the remote measurement clock is synchronized with the time base supplied by the 32786-Hz power signal. The block diagram in figure 1 shows a “15-channel” structure.

The coding-emission subassembly represented by the block diagram in figure 2 implements sampling, digitizing, sequencing (both internally and for the multiplexers of the amplifying subassemblies), PCM pulse train coding, modulation and transmission. Clock signals and carriers are generated via a phase lock loop. After digitizing over 12 bits with an additional parity bit, a synchronization word is inserted at the zero address of the cycle.

The message is then serialized and converted to a biphase signal, which is applied to two-state synchronous phase modulator prior to transmission. It also includes rectifying and stabilizing functions.
Figure 1: Structure of a "15-channel" System

Figure 2: Block diagram of the coding-emission subassembly
The amplifying subassembly includes four instrumentation amplifiers with programmable gain from 1 to 1000, 24 db/octave anti-aliasing filter, a multiplexer that can be cascaded with the ones in the other units, and rectifying and stabilizing devices for the power supply. It is driven by the coding-emission subassembly.

Figure 3: Block diagram of the amplifying-multiplexing subassembly

THE TECHNOLOGY USED

To reduce size and increase the MTBF, all the functions of the new units have been installed in a hybrid integrated circuit whose 25-by-50 mm chip contains five connecting layers. An ASIC supporting all the logic elements (PCM coder, PSK modulator, clocks, etc.) has been specially designed.

The hybrid circuits have been designed to guarantee the best possible reliability with this type of technology; the heat dissipation of the components has been monitored with special attention to minimize heat-buildup and to make the temperature distribution as even as possible on the surface of the chip which, at 125 degrees C, becomes very important and can severely damage the MTBF.

They are tested individually before being mounted on a 7-layer printed circuit board used to connect the hybrid to the two lateral terminal blocks.

The filter capacitors are the only components external to the hybrid.

The assembly is then mounted in cast aluminium cases filled with a resin that ensures proper mechanical behavior of the components.
MAIN CHARACTERISTICS

Rotor-mounted equipment

A series of modular units is available for building a machine-mounted system: power supply to the sensors (current or voltage), bridge closing branches, filters, amplifiers and conditioning, PCM coder.

The power supply to the units may either be d.c. (+/- 15/17V, +/-8/10V) or a.c. (11 or 22 V at 32768 Hz); each unit has its own rectifying and stabilizing devices.

All the indicated characteristics are applicable in the range of -20 to +125 degrees C and with a constant acceleration of 100,000 m/s^2. The burn-in and storage tests comply with the standards MIL STD 883 B.

- Power supply to the voltage sensor
  . +/-2.5 to +/-15 V, with a limit of 50 mA
  . drift under 0.2 %
- Power supply to the current sensor
  . 6 times 6.3 mA at 0 to 3000 Ohms
  . drift under 1 %

- Bridge closures
  . fourth bridge, half bridge, full bridge
  . 50 or 100 Ohm temperature probes
  . 120, 350, 1000 or 3000 Ohm strain gages

- Passive filters
  . high-pass or low-pass
  . Cut-off frequency upon request

- Amplifying/Multiplexing
  . 4 channels with differential amplifier
  . gains programmable by 3 bits:
    1, 15, 30, 60, 120, 250, 500, 1000
  . input protection
  . anti-aliasing filters
    24 db/octave
    cut-off frequency: 250, 500, 1000, 2000 Hz
    (as needed, depending on the number of channels)
  . zero drift: +/- 1 µV/degree C
  . gain drift: 10 ppm/degree C
  . precision of gain at 25 degrees C: 0.1 %
  . multiplexing control: 3 address bits and 1 mask bit
  . reliability (MTBF): 62,000 hours at 25 degrees C, 1300 hours at 125 degrees C
    (complies with standard MIL.HDBK 217 E)

- Coding/Emission
  . measurement rate: 25,000 or 50,000 per second
  . resolution: 12 bits
  . precision: 0.1% throughout the temperature range
  . multiplexing control for 1 to 63 channels
  . internal bit rate: 327 or 654 kbps
  . code: bi-phase or NRZL with parity bit
  . synchronization word with fixed profile of 13 bits
  . synchronous phase modulation (PSK)
  . carrier frequency: 6.55 or 10.48 MHZ
reliability (MTBF): 90,000 hours at 25 degrees C, 1783 hours at 125 degrees C (complies with standard MIL.HDBK 217 E)

Note: the coding-emission unit is stand-alone; it contains a broadband amplification channel (10 KHz) with an anti-reversal filter (30 dB/octave), which allows for using a SINGLE-CHANNEL system.

Central Equipment

All the necessary equipment is available from the catalog of SCHLUMBERGER Industries: the 32768-Hz power supply, the receiver demodulator, the bit and format synchronizer, etc.

Users can choose between a basic product such as the decommutator 8725 specifically developed for this system applications and the open, upgradeable DELTA system. The 8725 handles only digital reconversion functions for signals from the sensors. It includes PSK demodulation, bit and format synchronizing, decommutation and display of a channel on the front panel, as well as a parallel digital port for channels for data processing.

The far more sophisticated DELTA system, in addition to the functions handled by 8725, can be used to process the results, display them in real size, store them, compare them with threshold values, process them on workstations, etc.

CONCLUSION

This study was carried out on schedule and the results are generally better than expected. The performance levels for metrology, precision, pass-bands, measurement rate, etc., are excellent. The new modularity and reduced size allow for big savings, e.g., with respect to mechanically installing the modules on the machines.

The MTBF obtained (40 months instead of 18), amply meets the EDF objectives.

Although the main objective of this study is to integrate remote measurements into alternator monitoring systems, the results obtained provide a particularly effective instrument of measurement for rotating machines (electrical motors, pumps, steam turbines, alternators, etc.). The results also allow us to offer manufacturers a system capable of operating under extremely harsh environmental conditions with all the resolution and performance levels allowed by digital technics.
The technologies used and the new concepts have made it possible to create a product open to applications of all types.

Its size, low power consumption, range of operating temperatures (-20 to 125 degrees C), resolution (12 bits), adaptability and capability of operating under conditions of acceleration and vibrations (100 000 m/s² and 1000 M/s² from 20 to 1000 Hz), make it a unique product of its type.