Turbine Telemetry

For the qualification of jet engines intensive tests are necessary. Important information are strain, vibration and the temperature loads on the blades. The blades are the most critical parts of every turbine.
There are optical or direct strain measurement systems for measuring the loads in different operating modes. Currently the only proven method is the detection of the strain with strain gauges. Measuring the vibration amplitude with optical instruments is very limited in its use. The best way to detect the real loads of the blades is to apply strain gauges to measure the direct surface strain.
As the stress on the blades is increasing with new designs the acquisition of these data becomes more important.
The demand of a higher number of real-time measurement channels requires a more powerful turbine telemetry system to fulfil this task.
Figure 1 shows a typical test arrangement of a 296-channel installation and figure 2 a block diagram of the system. The 296-channel telemetry system typically consists of 96 dynamic high frequency channels (dynamic strain gauge inputs), 104 static strain gauge channels and 96 temperature channels for thermocouples. The static strain gauge channels are not always needed.

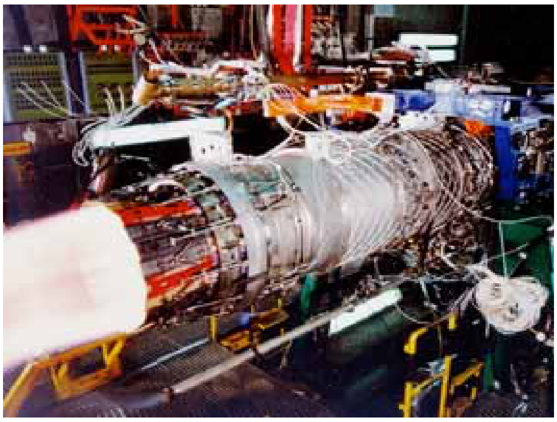

Figure 1 Typical test setup

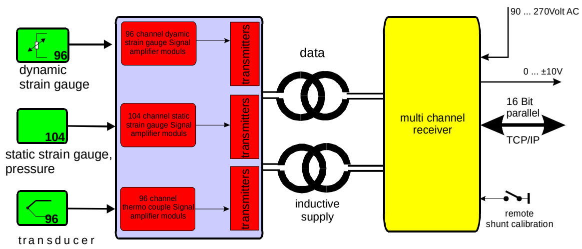

Figure 2 Block diagram of a typical turbine

The large volume of data depends on the dynamic strain gauge channels that are sampled at 100,000 to 200,000 times per second. As the temperature and static channels are normally only sampled 100 times per channel and per second an easy to handle low volume of data is generated. Previously it was not possible to transmit such a high data volume in real-time. The usual way to reduce the amount of data was to transmit only a part of the total amount of dynamic strain gauge signals at a time.

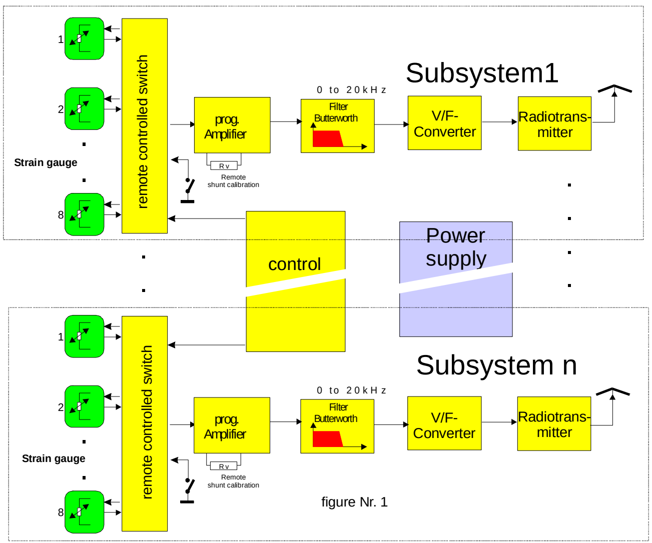

Figure 3 Typical remote controlled switching telemetry system

Classical remote controlled switching FM-Telemetry

Figure 3 shows the block diagram of such a typical remote controlled switching telemetry system in FM-Technology. The total numbers of monitored signals is divided in several subsystems. Each subsystem consists of an one-channel telemetry unit with a remote controlled switch in the front end that can handle for example 8 strain gauge signals. Within the subsystem only one channel can be monitored at a time. Every test run must be repeated according to the number of channels within a subsystem. For every subsequent test runs it is switched to further set of channel sensors of the telemetry by a remote controlled switch. The total test time increases by the number of inputs per subsystem. The set of strain gauges that can be monitored simultaneously is limited by the number of available subsystems. For example in case of a subsystem with 8 inputs there is an eightfold increase in test time and consequent cost. Due to the high stress load of the strain gauges the lifetime can be very short. It could be that one of the gauges in the remaining sets fails after measuring the first set of stain gauge that could result in the loss of that set of data. This is serious problem.

Another point is that data from different subset measurements are not comparable.

Despite of the fact that a remote controlled channel switching telemetry system is considerably less expensive the total costs (telemetry system and test run costs) for a complete testing are much higher and more risky. There are many reasons for a fully simultaneous working data acquisition system for all required channels.

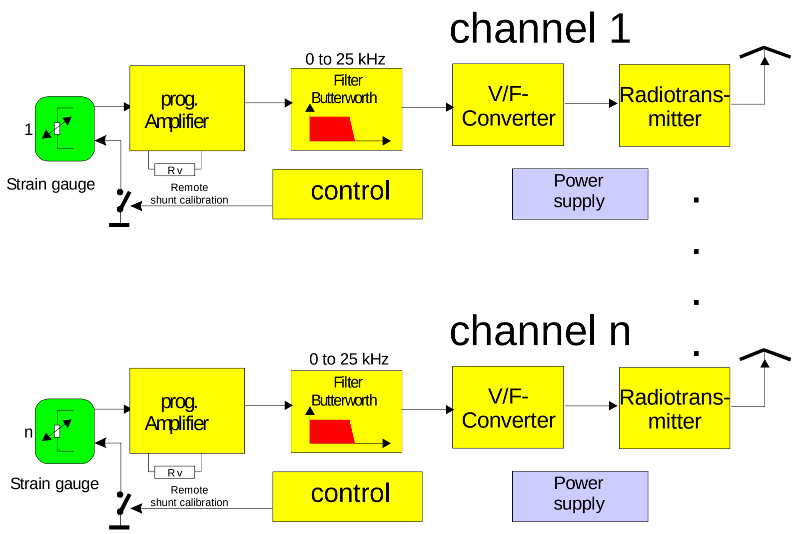

Figure 4 Block diagram of simultaneous operating FM turbine telemetry system

Figure 4 shows the block diagram of the full simultaneous operating FM turbine sensor telemetry system. This system avoids the previous problems. Every signal is fully separate and has it own supply. In case of damage to one signal channel there no effect to the others.
In case of a large amount of channels (for example 96) there are 96 different frequencies plus some for the static and the temperature channels. In principle it appears easy to handle 96 channels but in practice all frequencies changes over temperature and there is always a certain amount of intermodulation between the transmitters due the close mounting of all antennas. This intermodulation problem creates noise. Sometimes it is not possible to mount such a huge number of antennas due to the less available space. Also a big transmitting bandwidth for all channels is necessary. The problems increase with the number of transmitters. So it is nearly impossible to realize a good working system. Therefore an alternative solution it needed.

A digital working system delivers a much higher signal/noise ratio but also needs additional transmitting bandwidth.

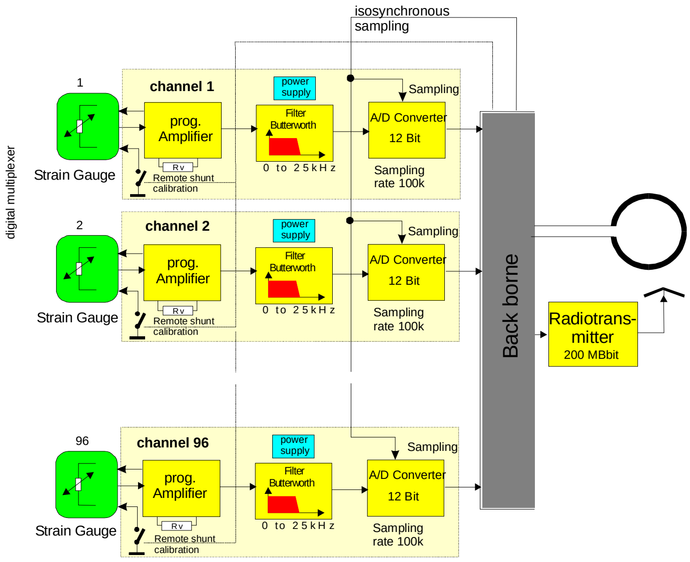

Figure 5 Block diagram of fully simultaneous working digital turbine telemetry system

Digital Turbine Sensor telemetry

Figure 5 shows the block diagram of the full simultaneous operating digital turbine sensor telemetry system. For every signal channel there is an fully separate programmable amplifier with anti aliasing filter and AD-converter. Every amplifier is remote programmable in gain and zero online via the telemetry line. Additionally there is a separate supply for every strain gauge and amplifier. That ensures that in case of a shortage in one strain gauge no effect is to the others. A voltage bridge supply enables a higher resolution of the signal than a constant current supply. The blades vibration-analysis inputs are normally AC coupled. The gain of every channel can be adjusted by very fine steps (12 bits) by remote control via the operating PC. For static channels a “Auto Zero” function is also available. To avoiding anti aliasing Butterworth filters are used. All A/D-converters work with a signal resolution of 12 bit and with isochronous sampling.

Figure 6 Manufactured turbine electronics

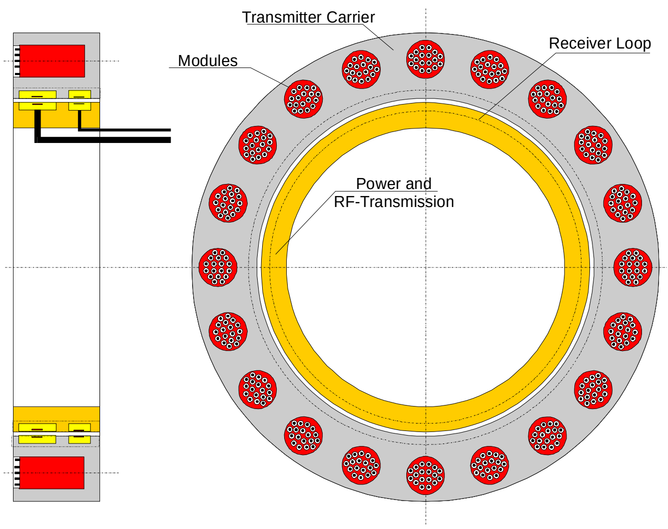

Figure 7 Typical mechanical structure of digital turbine telemetry turbine electronics

Figure 6 shows an example of a practical modular digital turbine rotor telemetry system. Each dynamic strain gauge module comprises 8 channels and the temperature module comprises 16 channels. In addition there is a transmitter module with is wired in a special way to produce very high reliability. Figure 7 shows the typical mechanical arrangement of the modules and transmitting device. There are 2 different transmitting lines – one for the power and one for the data. The rotor antennas are the outer loop as they are capable to withstand the high g load.

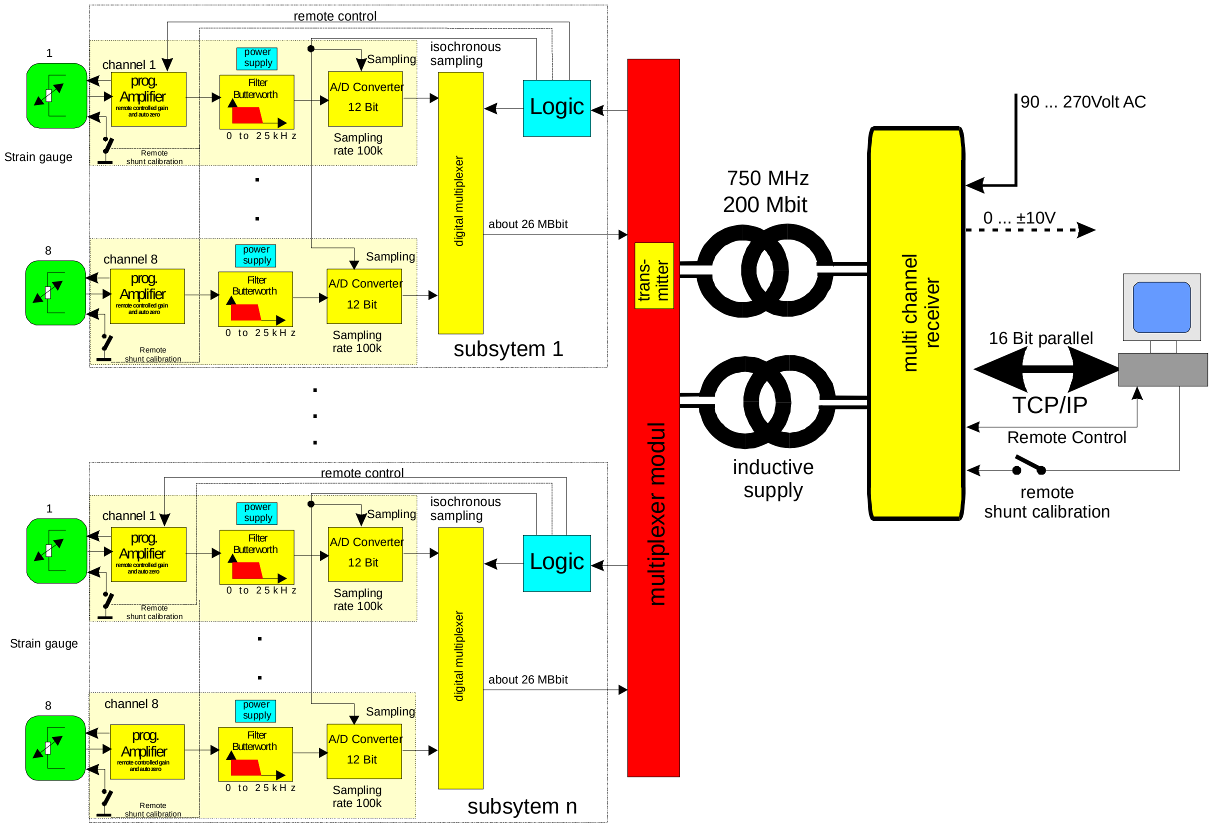

Figure 8 Block diagram of modular digital turbine sensor telemetry

In practice it makes sense to cluster 8 channels in one housing. Figure 5 shows such an arrangement. 8 channels are inside of every system (module) with the serial data streams combined by an integrated sub-multiplexing device. A common data stream via one wire flows to the backbone unit. Also the control signals and the power are wired separately to the modules. Inside the backbone there is a very reliable redundant transmitter. All modules work with isochronous sampling and there is only one serial data stream from the rotor to the receiver.

Digital data acquisition direct with computer

The big advantage of digital turbine telemetry is that the digitizing is carried out inside the rotor electronic. In classical systems the digital data is converted in analogue signal and recorded on paper. However the analysis of this recorded data is very time consuming.

The better way is to record directly the total amount of the digital signals to the computer. Today it is possible to record all data by a powerful computer in real time. This allows automatic and detailed analysis of the data. For correct analysis it is important that the signals are recorded in time-aligned form. The system structure shown in figure 8 has a big advantage. The system shown transmits only one data stream that is already time aligned and includes all data (dynamic strain gauge, static strain gauges and the thermocouple channels). This data can be transferred directly to the computer. As a result the receiver now becomes very simple as it only supplies the rotor power and recovers the serial data stream. The recovered data is directly transmitted to the computer with the simplified receiver resulting in a lower cost system.

Redundancy

Despite of the big advantage there is one critical point. What happens when the transmitter fails? As tests on turbines are very expensive and the telemetry is normally mounted inside the turbine any repair is time consuming and costly. It would be a catastrophe if all channels were lost in the event the transmitter fails. In order to avoid this problem a redundancy system concept is necessary.

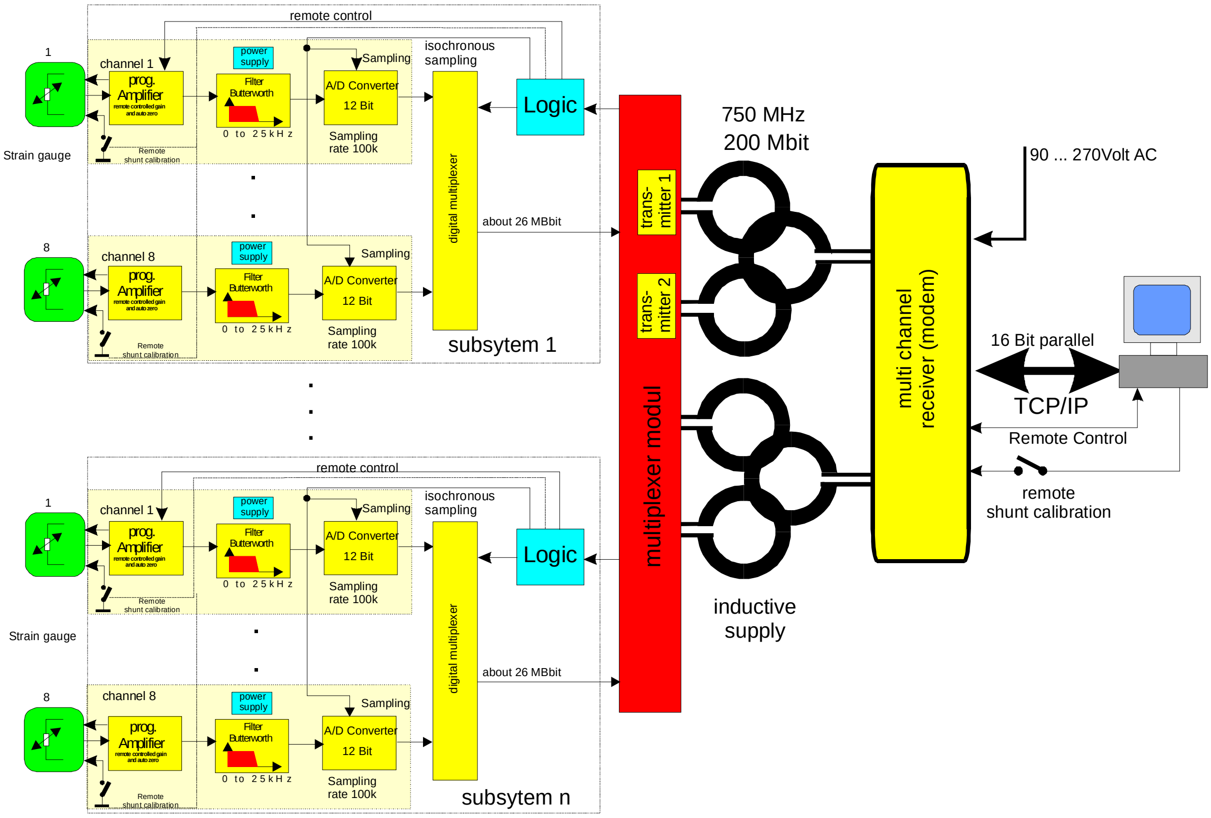

Figure 9 Block diagram shows digital turbine sensor telemetry with redundancy

Figure 9 shows such a structure where the transmitter is redundant and there are 2 transmitters inside of the transmitter modules and 2 transmitting antennas. Failures can also occur on the rotor loops (power loop and rotor antenna) that are highly loaded resulting in destruction. Both transmitters can be activated remotely from the receiver side. In case of failure of transmitter N°1 the transmitter N°2 can be activated. The concept of redundancy is a good solution to any component failure. Failures inside the modules have no effect to others.

Remote Control

The input span of the signal can be adjusted remotely by the PC. This is important to set the input range to the real existing signal amplitudes during tests in order to get the best resolution. The adjustment of the span can be done in small steps with a resolution of 12 bits. For static channels the “Auto Zero” function is available.

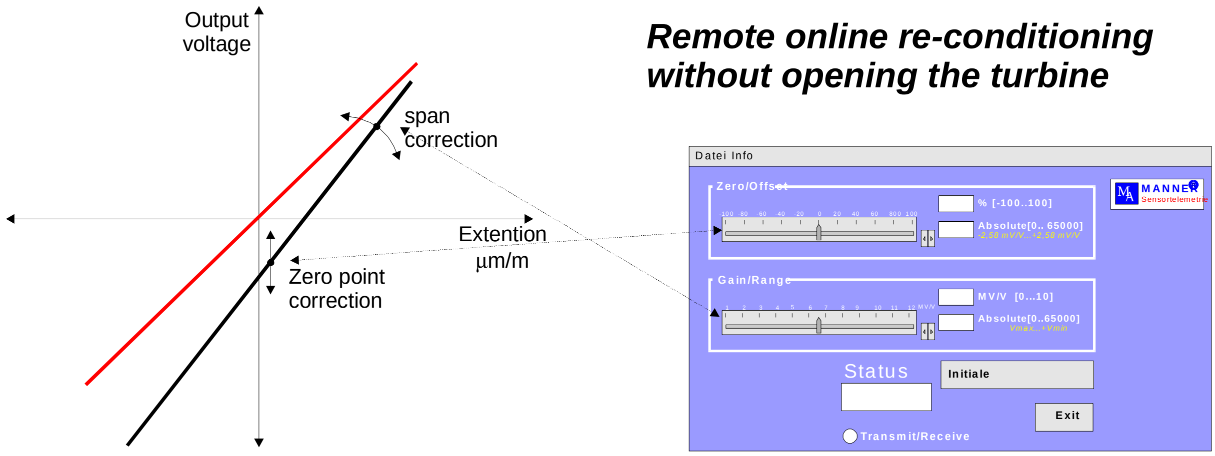

Figure 10 Remote Control

Practical arrangement

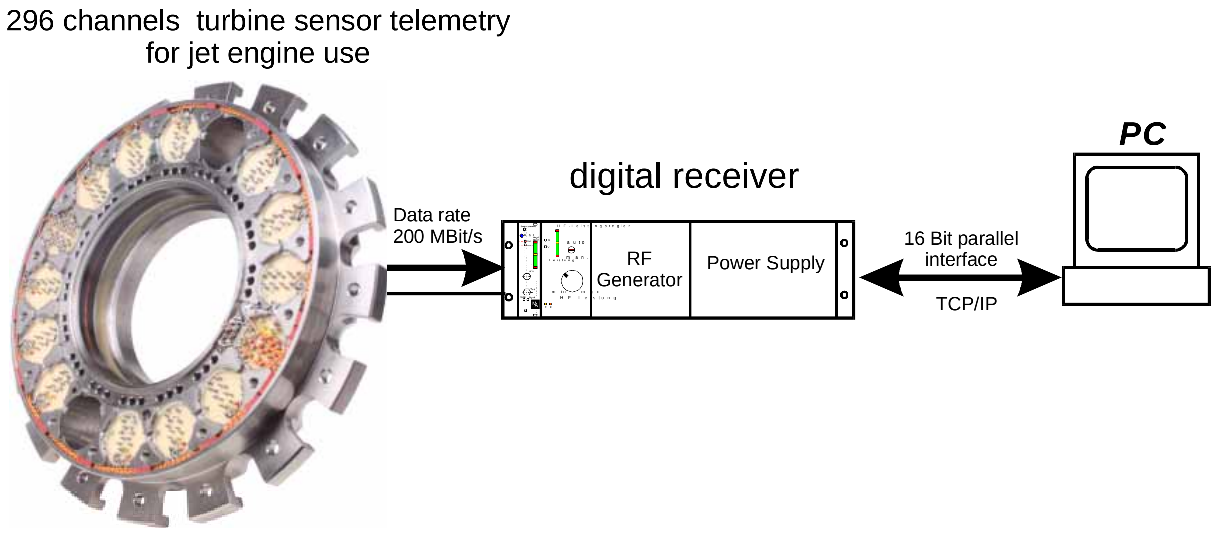

Figure 11 Practical arrangement of the 296-channel digital sensor telemetry system with redundancy

Figure 11 above shows the practical arrangement for the redundant digital turbine sensor telemetry system. As the data is directly transmitted via the digital receiver to the computer no additional data acquisition system is necessary.

Summery

The digital turbine sensor telemetry has following advantages:

- High channel count (up to 300 channels)
- Simultaneous synchronized data acquisition for all channels (no bank switching)
- Shorter testing time due simultaneous data acquisition for all channels
- High signal bandwidth per channel up to 50 kHz
- Redundancy concept
- High resolution of the signals, signal noise ratio better 56 dB
- No crosstalk
- Direct data acquisition with the computer
- Simple receiver