The Rotor-Signal-Module of MFI90

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Abstract

This paper presents special measuring equipment designed for acquiring rotor data from a BO105 helicopter. Some aspects of hardware design, especially in the field of digital data acquisition and processing will be discussed. On this occasion the limited space available on the rotor hub must be taken into consideration. The rotor-signal-module also has to function in the future measurement system MF190. The paper concludes with the presentation of a method of calibrating the measurement values from the rotor blades. In this connection measured rotor data will be compared with results obtained by a nonlinear helicopter computer simulation. This represents one possibility to check the data quality.

1. Introduction

The acquisition of data from the rotating rotor blades of a helicopter has significance in the field of system identification and structural mechanics.

The aim of system identification is the mathematical modelling of helicopter dynamics. Therefore it is of interest to know the direction of the lift vector and its modulus. The vector can be calculated from the movement of the rotor blades. This is also relevant to applications of helicopter control systems like inflight simulators. The investigation of blade deflection under load and its form of vibration takes place in the area of structural mechanics.

Figure 2 first shows a typical time history of measured rotor data (all shown data is obtained in a BO105 helicopter).

Figure 1. The DLR's BO105 helicopters

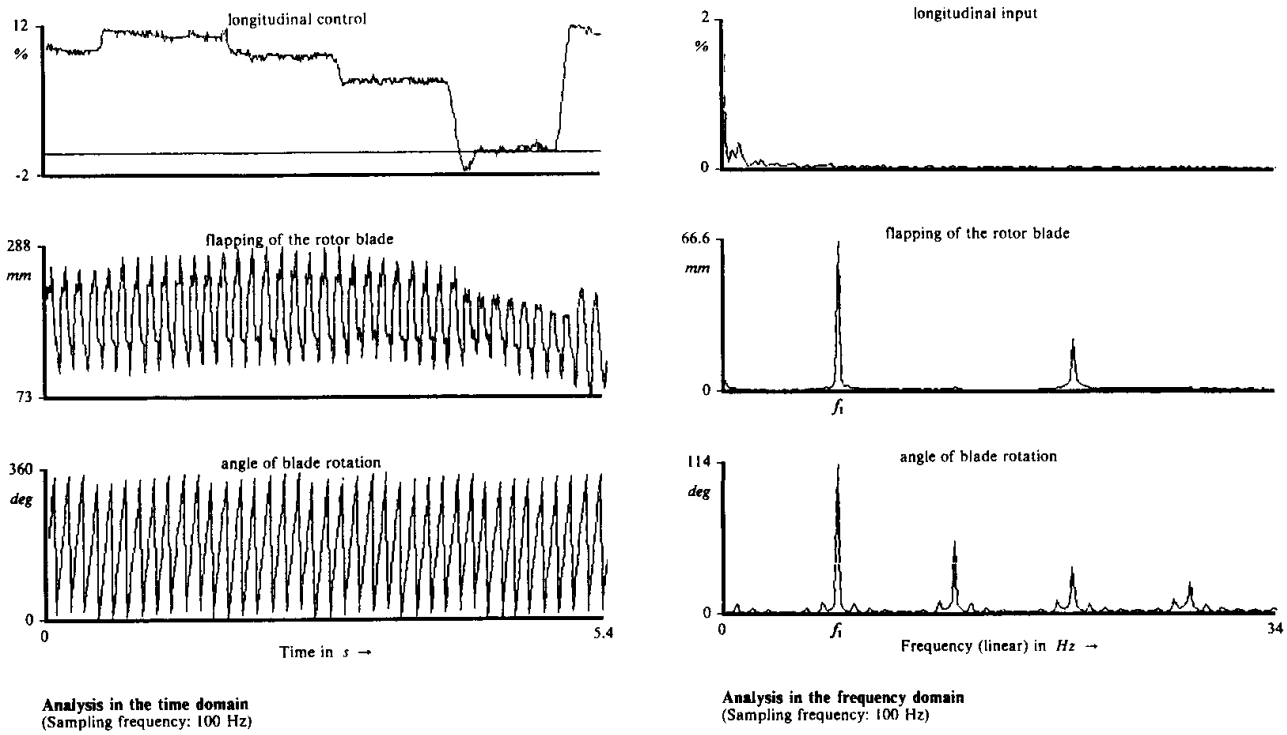

Figure 2. Presentation of rotor data in time and frequency domain

The generation of lift and speed by means of a rotating rotor produces flapping of the rotor blades. The longitudinal control input influences the flapping (sec figure 2). But the angle of blade rotation is determined by the rotational speed of the rotor which is constant. For this reason the angle has a linear shape within one rotation. Both flapping and angle of rotation contain the same fundamental frequency f_1 corresponding to the rotational speed (see figure 2).

The higher harmonics of the flapping frequency are of interest for investigations in the area of structural mechanics. The quantity of measured harmonics depends on the blade azimuth position measured. The measuring point related to the measurement in figure 2 is located close to the beginning of the blade where the bending moment is a maximum (see figure 3).

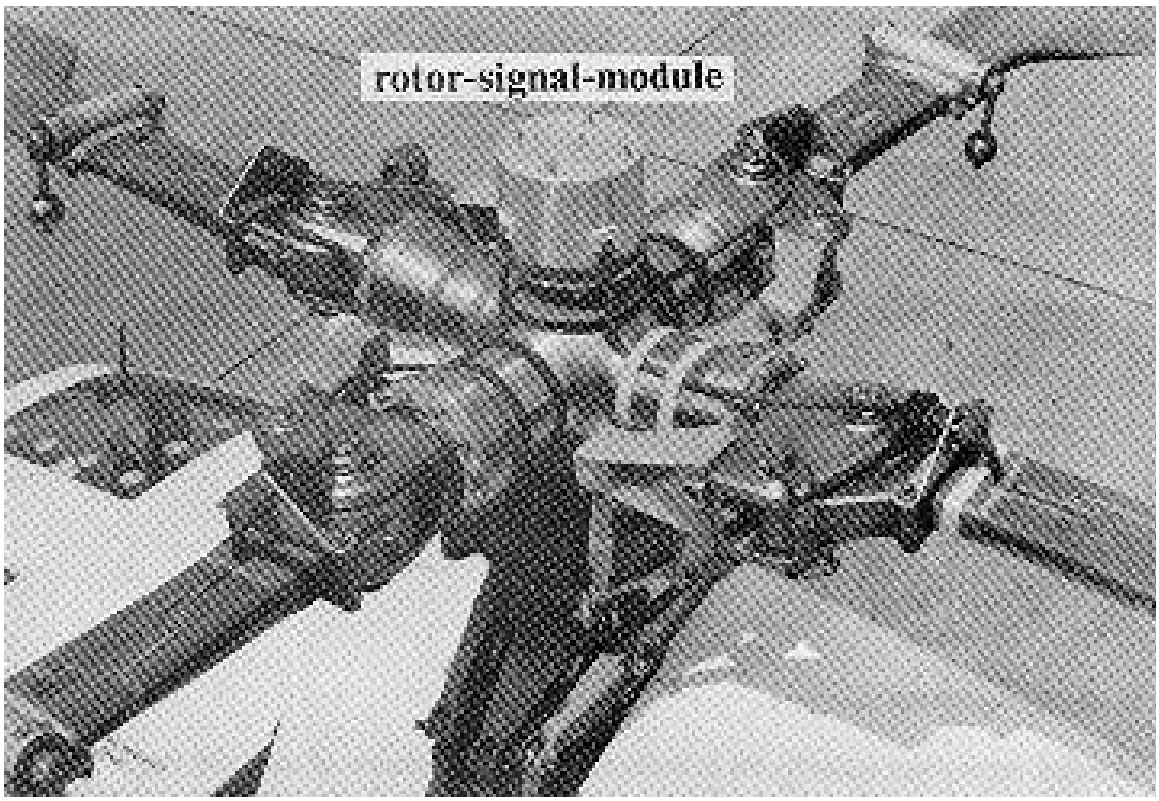

Figure 3. Measuring equipment on the rotor

For the purpose of system identification this measurement value is related to the deflection at the end of the rotor blade. The measurement is obtained by a resistance strain gauge.

The blade control angle for each rotor blade is another relevant quantity.

2. Measuring Equipment Design for Rotor Data

2.1 General

The total amount of measuring points for each rotor blade, the sampling frequency and the restricted number of slip rings must be taken into consideration when designing measuring equipment for rotor data.

Figure 4 illustrates the structure of measuring equipment.

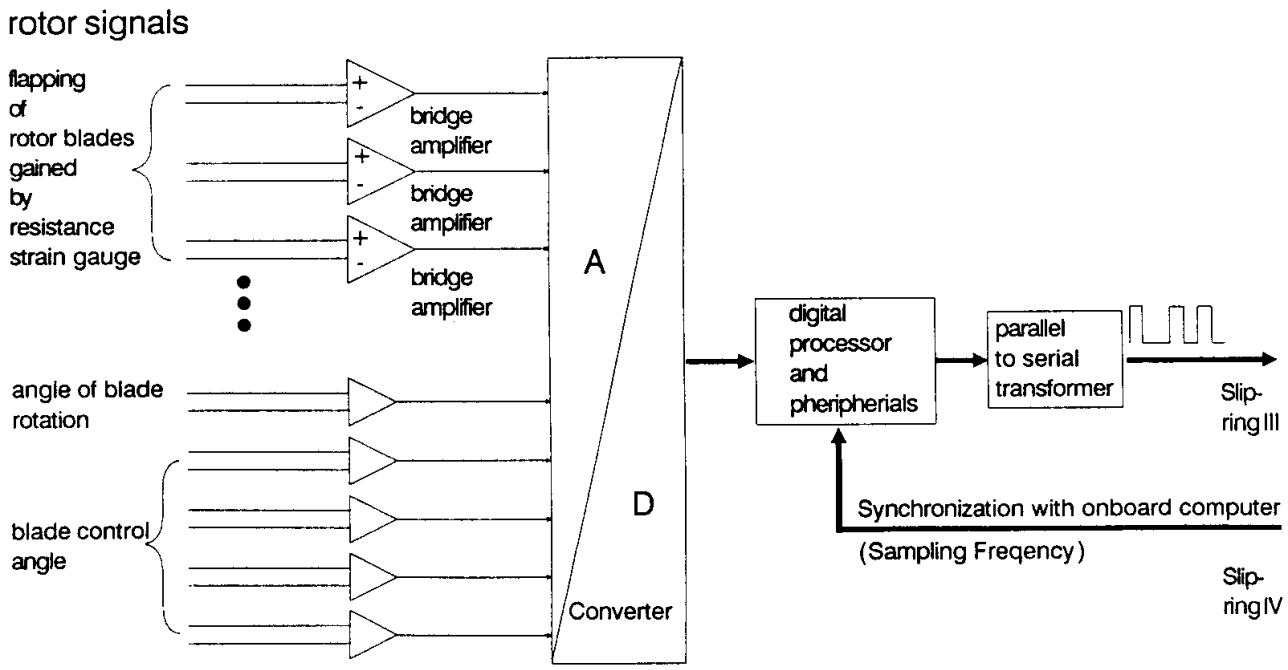

Figure 4. Measuring equipment structure

The data transmission takes place serial by bit in order to reduce the amount of used slip rings. Two slip rings are necessary for power supply and one for the synchronization with the recording onboard computer. All transducer signals need amplifiers to fit their voltage range to A/D converter input.

2.2 Sampling Frequency

Because the space for measuring equipment on the rotor hub is limited (see figure 3) the needed hardware should be reduced to a minimum.

If the sampling frequency can be chosen high enough, it is the best way to carry out the digital conversion directly after the transducer without using anti aliasing filters. With this method the hardware for analog filtering can be omitted. On the other hand the frequency

information of the measured values is high. It is not determined by the cut-off frequency or a low-pass filter.

The high amount of data is a disadvantage. Therefore the sampling frequency should be as low as possible. It must be chosen in a way, so that no aliasing errors will occur in the spectrum of interest.

Figure 5 demonstrates the effect of aliasing in frequency and time domain.

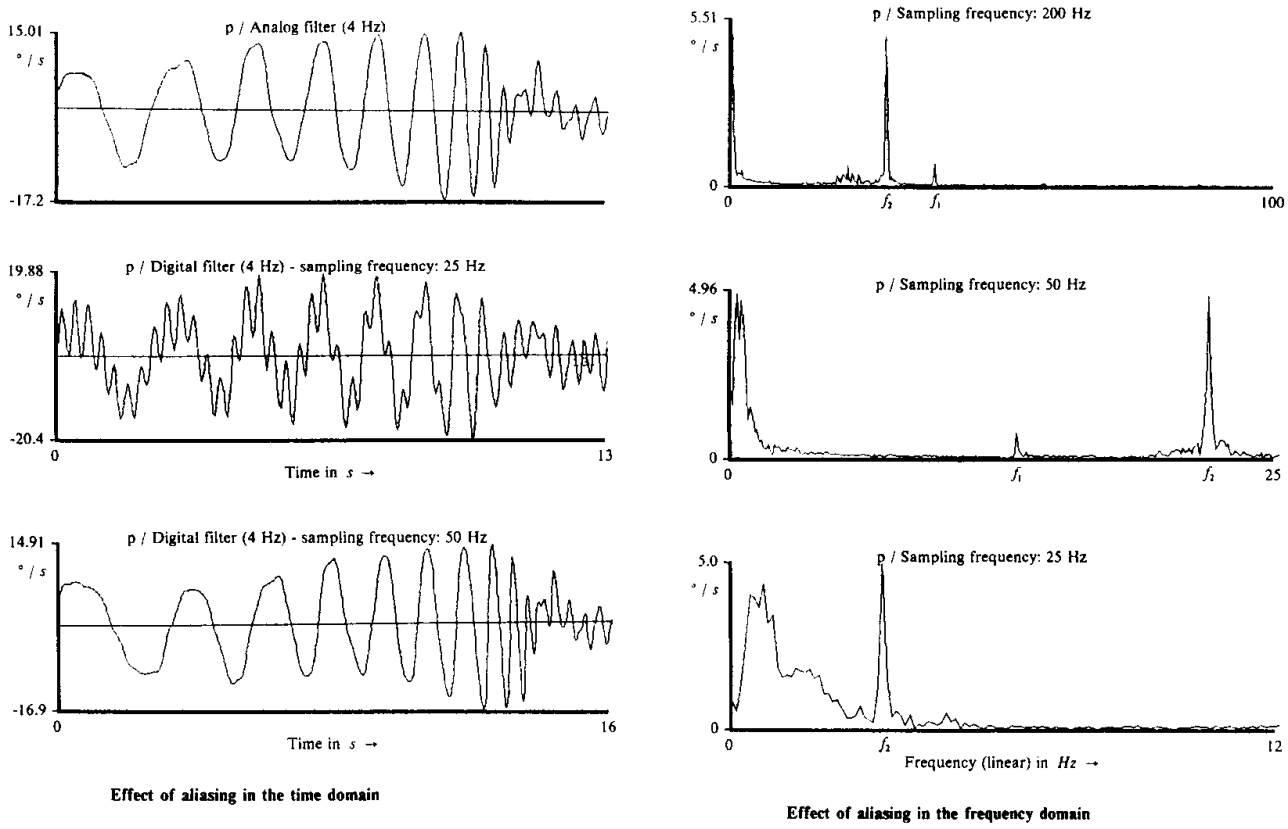

Figure 5. Effect of aliasing in frequency and time domain

The measured pitch rate is obtained in a BO105 helicopter. The frequencies f1 and f2 are caused by the flapping of the rotor blades which becomes noticeable as vibrations in the entire helicopter.

The aliasing errors produced above the spectrum of interest (sampling frequency is 50 Hz), which in consequence of the undersampling can be suppressed by subsequent filtering of the data in a digital computer. But aliasing errors in the base-line spectrum cannot be suppressed by digital filtering (sampling frequency is 25 Hz). The sampling with 100 Hz of the flapping signal (see figure 2) produces no aliasing errors, although other measuring

points on the blade can produce higher harmonics of the flapping frequency. To avoid aliasing it is necessary to use sampling frequencies up to 300 Hz.
(References [1], [2]).

2.3 A/D-Converter

The response time should be as low as possible for data transmission after the sampling is triggered by the onboard computer. This demand comes from a real time application for inflight simulation. Therefore the time for A/D-conversion should be as low as possible.

Two types of A/D-converters are available for fast conversion: a converter with successive approximation and a flash converter. In order to save space in the design of hardware an analog multiplexer should be included on the A/D-chip. Consequently such a special converter with successive approximation has been chosen.

For that reason it is meaningful to use sample and hold amplifiers. They elliminate time shifts between simultaneously sampled data caused by the A/D-conversion time. This conversion time also produces a signal disturbance when no sample and hold amplifiers are used. The disturbance which increases with signal frequency reduces the bit resolution of the A/D-converter.

2.4 Digital Processor

The demands for a digital processor are:

1 . Control of A/D-conversion

2. Control of data transmission

3. Calculation of relevant data from the measured values / especially for real time applications

Demand 1 and 2 are tasks with minimal workload, which can be done by every available microprocessor.

The demand 3 of calculating data requires a microprocessor with fast floating point arithmetic. This real time requirement also leads to a high speed data transmission.

One new microprocessor called transputer (figure 6) has a hardware structure to accomplish these tasks.

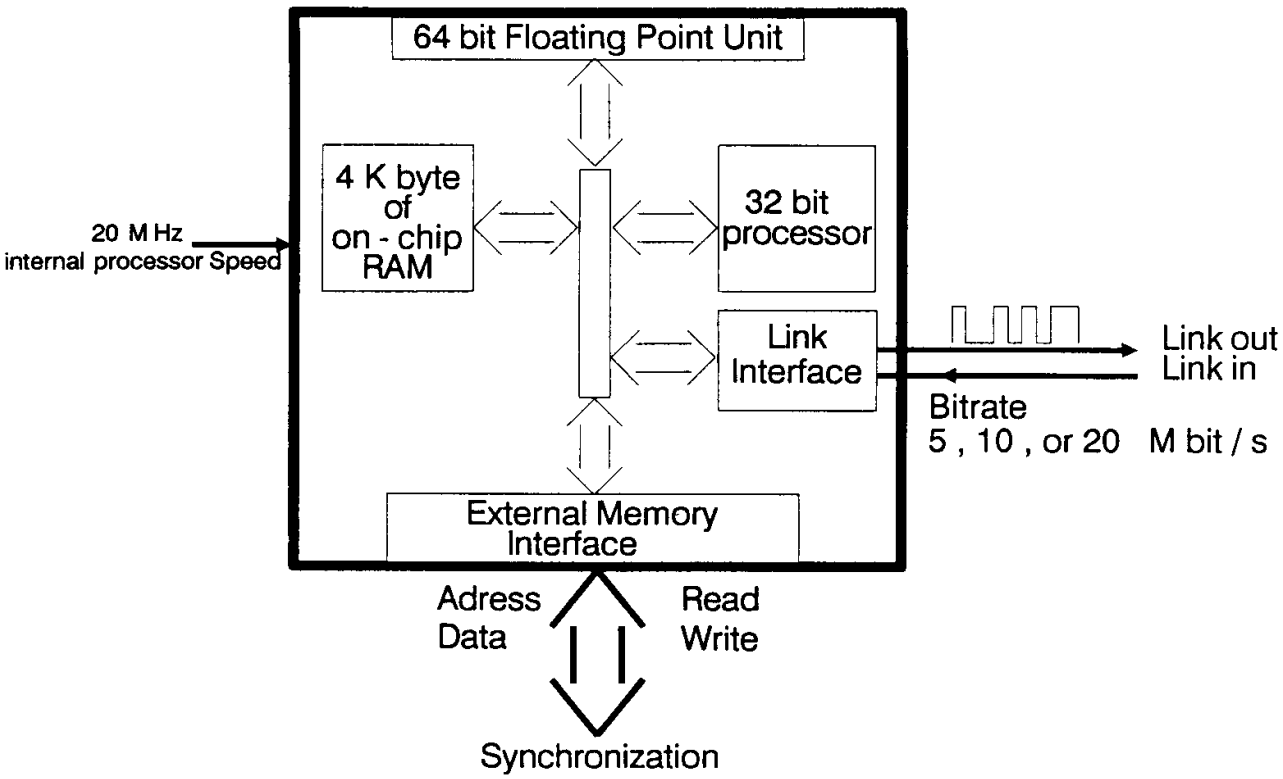

Figure 6. The transputer T800 block diagram

Figure 6 contains the essential features of a transputer required for real time data processing. A transputer is a 32 bit RISC-processor with a 64 bit floating point unit. Another important feature is the LINK-interface with data rates up to 20 Mbit/s. Each transputer has four LINK-Interfaces on a chip. The special software language OCCAM supports an easy networking of several transputers by LINKs. This feature is important for the design of a modular measurement system like MFI90.

For the purpose of acquiring and transmitting data another microprocessor was also used. This 8 bit microprocessor (8085) only controls the A/D-conversion and the transmission of data. The data transmission takes place by means of USARTs in RS232 mode. This is a well-tried computer standard. A disadvantge of RS232 mode transmission compared with transputer LINKs is the low transmission rate (up to 19.2 Kbit/s).

The hardware for data acquisition (amplifier A/D-converter and digital control) is the same for both processors. The two processor boards can be replaced without changing any other hardware (see figure 7). The 8 bit processor was used because it is easier to handle in some cases than the transputer. But the 8 bit processor can only be used for data acquisition with low data rates and no real time calculations.

Figure 7 shows the rotor-signal-module, the onboard control computer (DEC LSI 11/73) and the floppy disc for data recording.

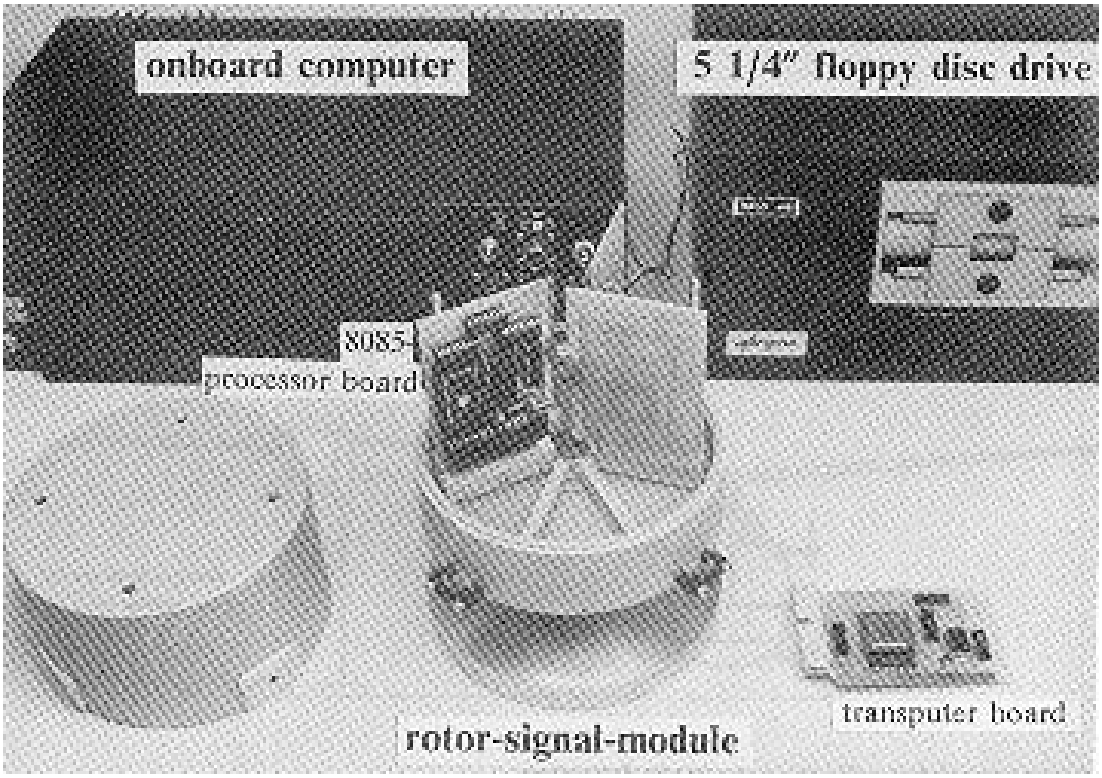

Figure 7. Rotor-signal-module in conjunction with onboard computer and floppy disc

(Reference [3]).

3. Calibration of Rotor Data

In order to obtain rotor data for calculating relevant helicopter quantities it is necessary to create a useful calibration. The problem is to find a physical reference which can be simply measured. The deflection at the end of each rotor blade as a consequence of lift and centrifugal force can be used for such a calibration.

Figure 8 demonstrates the procedure for calibrating the blade deflection.

A small needle is attached to one rotor blade. This needle is used for scratching a hole in a polyfoam, block. The polyfoam block is fixed on a stick which will be tilted to the rotating rotor. The pilot lifts the rotor blades all at once by using the collective control. With this kind of supervision some steady blade deflections will be measured. They will be measured simultaneously with rotor data obtained by the resistance strain gauge. For these data pairs a linear correlation has been estimated. The procedure has to be repeated for every rotor blade.

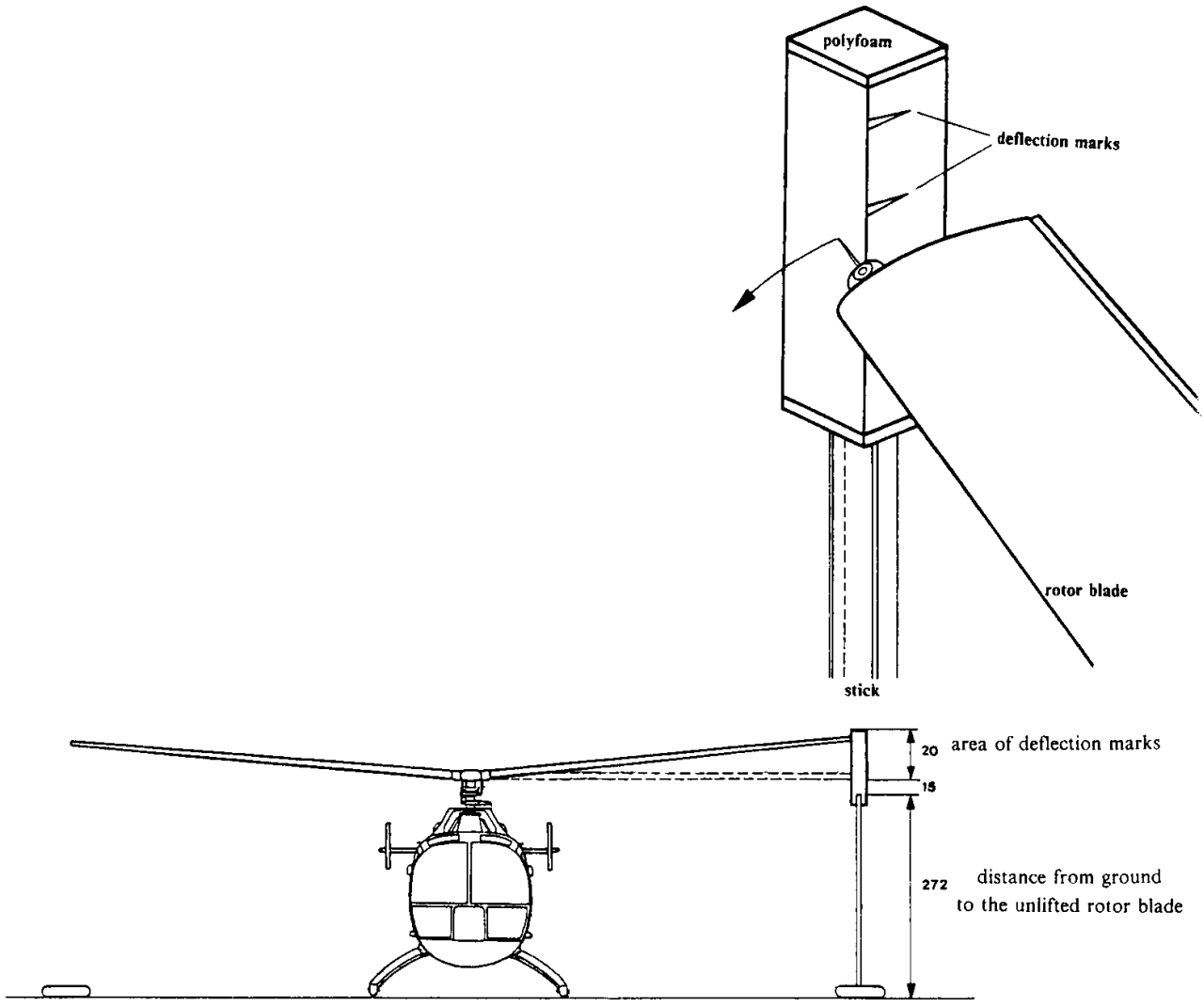

Figure 8. Arrangement for calibrating the blade deflection

The lift of rotor blades is limited during the calibration because the helicopter is not allowed to change his ground position. The limit is reached when the lift force is equivalent to the helicopters weight. Due to security reasons the pilot must remain under this limit.

(Reference [4]).

4. Data Check

The checking of measured data during a flight test realization causes a problem.

When the quality of measured data describing the helicopters solid-state movement shall be checked, relations between the rotational velocities and the attitude angles can be used. There also exists differential equations between the linear accelerations and the linear

velocities. Figure 9 for example, demonstrates the result of a wrong dynamic relation between the roll angle and the roll rate. On the other hand it shows a good correspondence between the measured pitch angle and pitch rate.

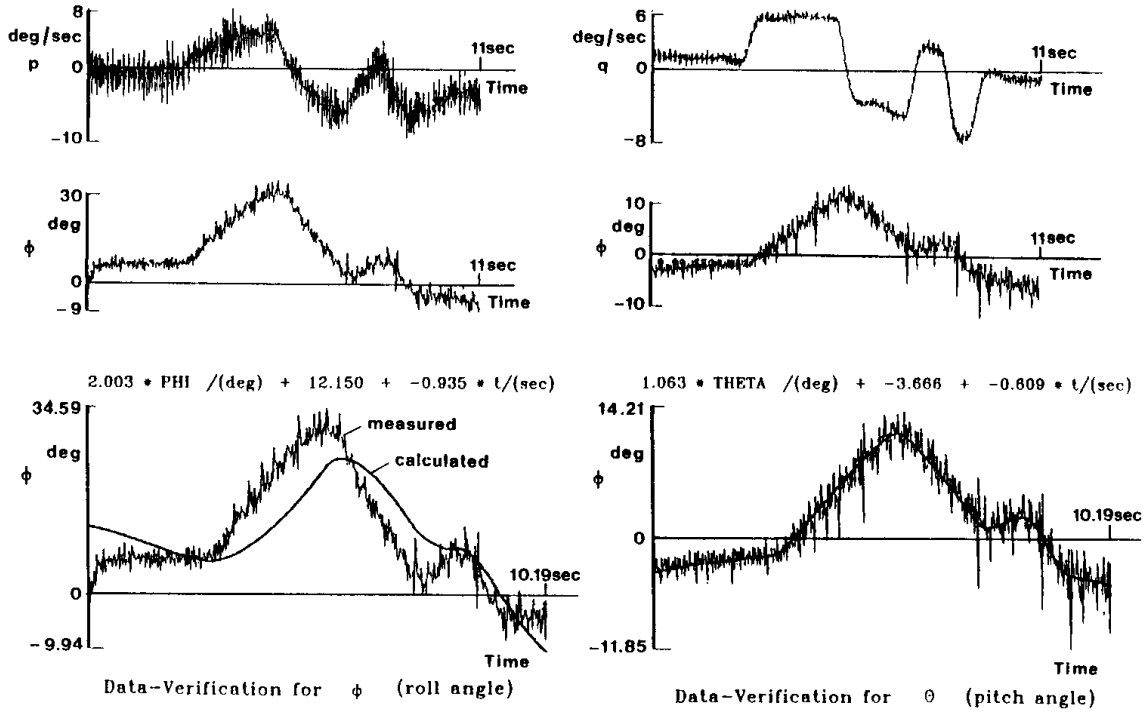

Figure 9. Data checking for compatibility in the field of solid-state movement

In order to check rotor data it can be useful to have such redundant measurements as realized for solid-state movement. We have checked the rotor data by comparing them with results obtained from a nonlinear helicopter computer simulation.

Measuring the deflection (flapping) of all rotor blades and the angle of blade rotation enables the calculation of a tip path plane (figure 10). Three calculated quantities, the longitudinal and lateral flapping as well as the coning are relevant. The longitudinal and lateral flapping describe the slope of a tip path plane around the corresponding axis. The coning represents the angle of the common blade deflection.

Figure 11 shows the results for a longitudinal control input on the BO105 helicopter.

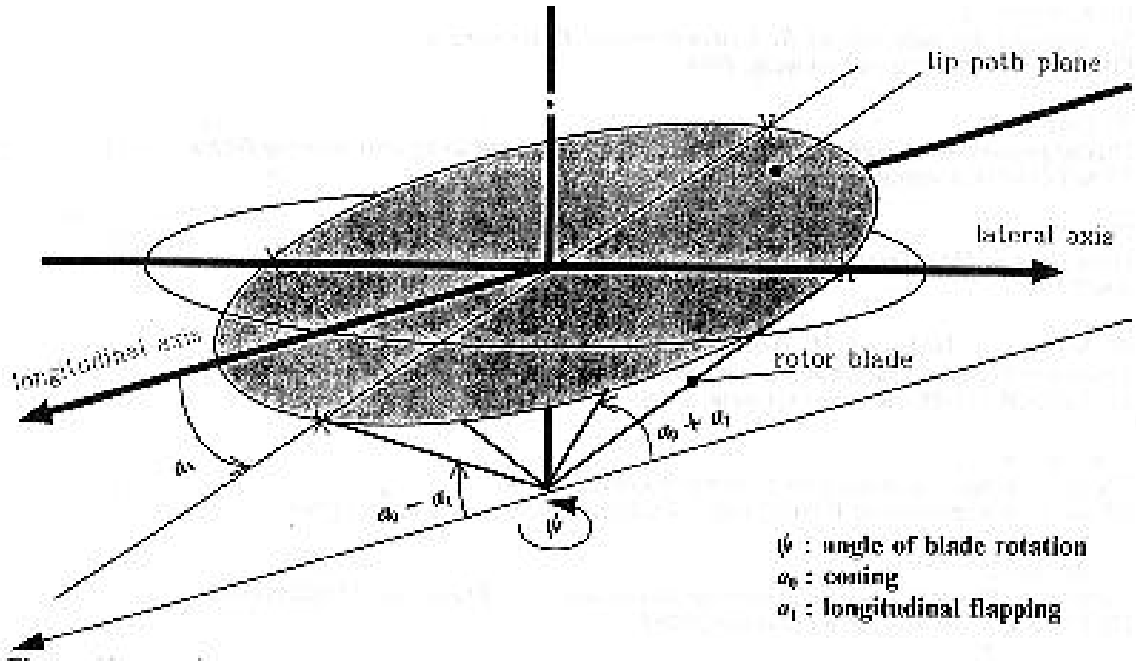

Figure 10. Calculations of relevant rotor data

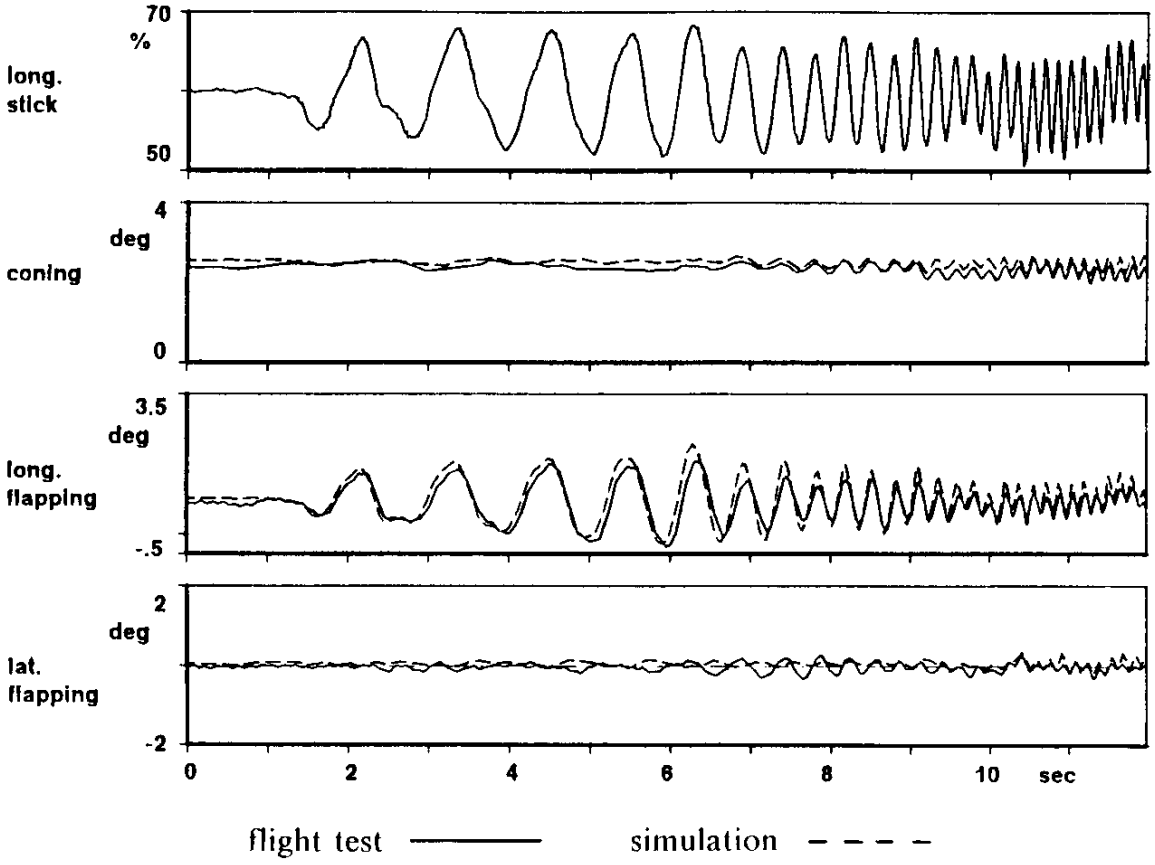

Figure 11. Comparing flight test rotor data with simulated rotor data

(References [5], [6], [7]).

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