GERMAN TELECOMMAND STATION-THE DYNAMIC BEHAVIOUR OF THE STEEL STRUCTURE AND ITS DRIVE AND CONTROL SYSTEM

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Summary. The mechanical equipment and steel structure of large antennas represents a vibratory system made up of very many elastically coupled masses. Together with the drive control equipment, this complex system has to meet certain requirements with regard to pointing accuracy, turning range, turning speed, and acceleration. Prior knowledge of the dynamic behaviour of the whole control loop is essential to avoid unpleasant surprises at the commissioning stage.

1. Introduction. In the case of the German Telecommand Station mathematical models were developed to allow calculation of the eigenfrequencies and mode shapes of the antenna. Mathematical models were also used to provide the basis for the design and to simulate the drive control mechanism. With the aid of investigations using analogue and digital computers, a kinematically optimal control concept and antenna design was found by varying the control parameters and the model structure.

The paper describes the model studies and the drive and control systems. In the oral presentation some additional information will be given based on evaluations which will be completed in the period after submission of the paper.

2. Dynamic Equations and the Vibration Behaviour of the Mechanical Structure. The mechanical part of the antenna consists of the steel structure and the gears and drive motors for positioning the antenna in elevation and azimuth. In order to mathematically describe the dynamic behaviour, the whole complex entity must be formally represented by a spring-mass system. Formalized in this way however, the characteristic properties of the structure's behaviour must not be obscured.

Assuming that the structure is formally represented as a combination of point masses and spring elements, each point has a maximum of six degrees of freedom in space, i.e., three in translation and three in rotation. The equations for determining the eigenfrequencies are:

$M\ddot{x} + Cx = 0$

Where M is the mass matrix
C is the stiffness matrix
x is the vector of the degrees of freedom

The eigenfrequencies and mode shapes of the spatial elevation-azimuth model were calculated for a total of 61 degrees of freedom. But in the further studies, especially for the simulation of control behaviour, the number of equations had to be reduced. However, it was apparent from the vibration modes that azimuth and elevation vibrations are largely decoupled. It was thus possible to simplify matters by using two decoupled models, i.e., one for azimuth and one for elevation, at the same time reducing the degrees of freedom of these subsystems.The simplified models for azimuth and elevation each contain only 12 degrees of freedom.

Nonlinearities play a part in the simulation of control behaviour, e.g., friction in the bearings, and backlash and friction in the gears. The linear system of equations used to determine the eigenfrequencies therefore has to be expanded to take account of nonlinear terms. Attention also has to be given to the damping ratio of the structure.

The equations which describe the dynamic behaviour of the structure (i.e., the controlled system) are therefore:

$$M\ddot{x} + D\dot{x} + Cx + N(x, \dot{x}) = R$$

Where D is the damping matrix,
N is the matrix containing the nonlinear terms in x and $\dot{x}$
R is the vector of external forces including drive moments and wind force.

3. Simulation of the Control System. A control concept of the kind in Fig. 1 served as the basis for the studies of the control system behaviour. ANAGOL was the program language for the simulation with a digital computer. This language permits simulation problems to be fed into the computer both in block-oriented notation and in algebraic notation, thereby allowing as many nonlinear and time-variant differential equations as required. The simulation program for the decoupled azimuth and elevation models were each made up of approximately 400 blocks. In view of the sign functions in the system, the Euler process was used for integration. In order to assure stable computing runs, an integrating increment of $\Delta t = 10^{-4}$ sec had to be applied on account of the nonlinearities.

Two curves obtained from the azimuth model may serve as an example of the simulation results. The two curves show the behaviour of the system under a load set up by a gust of wind, where the wind speed increased from 0 to 50 km/h in 100 ms and then remained steady. The curves in Fig. 2 show the rotational speed of the antenna and the mean speeds of all the drive motors. Figure 3 shows the transient response to the error in angle of the antenna from the same gust of wind. As can be seen, the antenna has kept within the maximum allowable dip of 0.01° and after 1 second the 0 error in angle is only 0.001°.

4. Drive and Control System. Special d.c. motors are used to power the drive. These are motors of excellent dynamic performance (e.g., similar to those used for feed drives on machine tools) which have been specially adapted for this particular application. Major characteristics of these motors are linearity between armature current and torque up to approximately ten times the rated current of the motor, low moment of inertia of the rotor, and low armature time constant. All motors are equipped with PTC thermistors. Tachometer generators connected directly to the motors are used to measure speed.

The drive system is electro-mechanically tensioned to eliminate backlash in the gears and so enable the antenna to be moved into new positions and at very low speeds without any jerks. The drive motors for azimuth and elevation are each divided into two groups which work against one another at different torques. The compensation of heavy gusts of wind represents the only case in which all motors of an axis work together in the same direction of torque.

The d.c. motors are supplied from contactless, maintenance-free thyristor static converters for 4 quadrant operation arranged in cross-connection with circulating current.

The control system comprises a primary position control with a secondary speed control and a subordinated current control (Fig. 4). The speeds of the individual drive motors are used for compensating speed fluctuations of individual motors or groups of motors (damping circuit 1). The rotational speeds of the antenna in azimuth and elevation are used for damping vibrations in the mechanical structure (damping circuit 2).

These rotational speeds are measured with the aid of tachometer generators mounted directly on both axes of the antenna without interposed gears. Rotary inductosyns, likewise directly mounted, collect the position actual values in azimuth and elevation.

The reference limiter represents an additional component which was specially developed for this application. It converts step-function position setpoints into corresponding command values for acceleration, velocity and position with due regard to limitations inherent in the equipment. This enables the controllers to be largely relieved of such work in the interests of higher setting speeds. The reference limiter also adjusts the various modes of operations (e.g., programmed computer control, manual speed and position control, and, in a second extension phase, control via an autotracking receiver) to the dynamic behaviour of the whole control loop. During computer operation the discontinuous input of position setpoints is converted into continuous input.

5. Some Results achieved. Extensive acceptance tests were made upon completion of the antenna, which was found to comply fully with all points of the specification.

A few figures will serve to show the kinematic characteristics of the antenna:

Lowest eigenfrequency	in azimuth :	3.5 Hz
	in elevation :	2.5 Hz
Speed range	in azimuth :	0.0015°/sec
(jerk-free drive)		to 1.5°/sec
	in elevation :	0.001° /sec
		to 1.0°/sec
Pointing accuracy	in azimuth :	0.001°
	in elevation :	0.001°

6. Conclusion. The development of the German Telecommand Station Antenna has demonstrated the enormous advantages of very close cooperation between the manufacturers of the mechanical part of the equipment and the manufacturers of its drive and control systems. Valuable knowledge relating to the design and construction of the antenna and its drive and control systems was gained very early in the planning stage with the aid of model studies and simulations. The completed plant has fully satisfied all expectations.

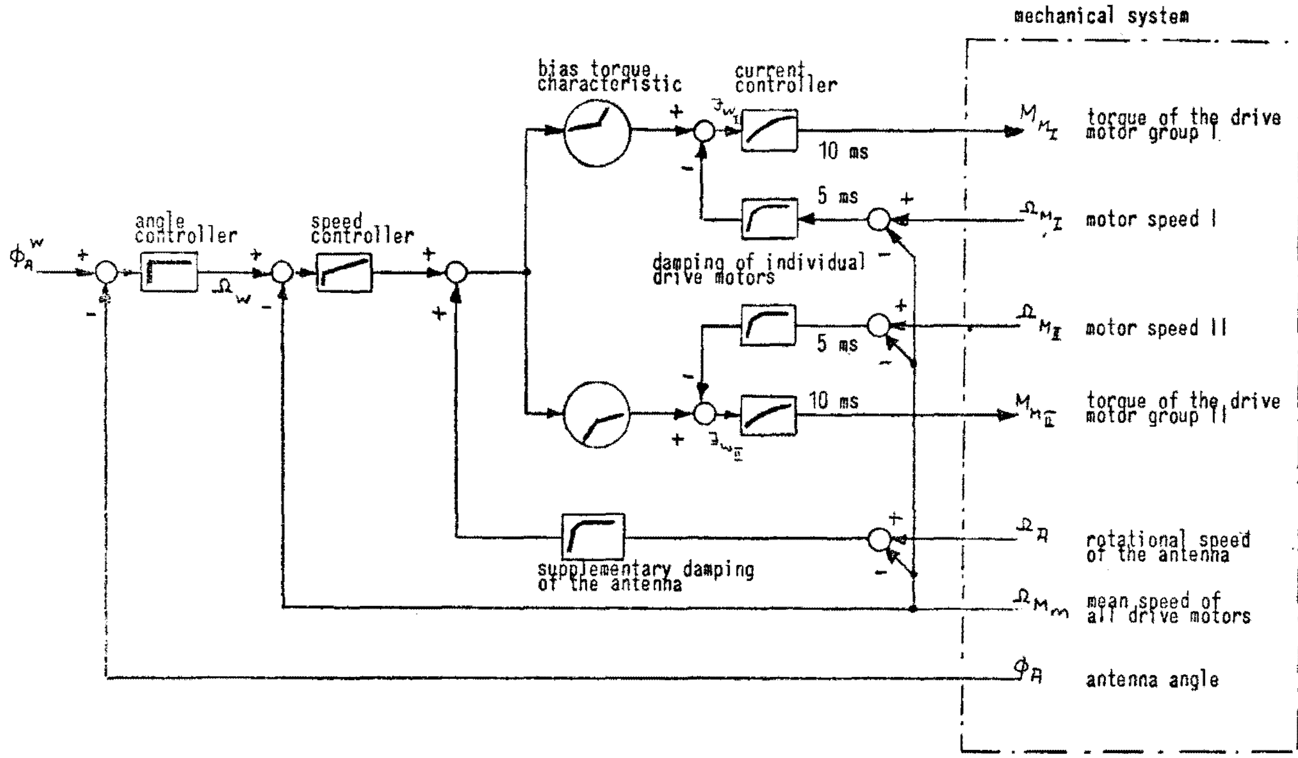

Fig. 1   Control concept

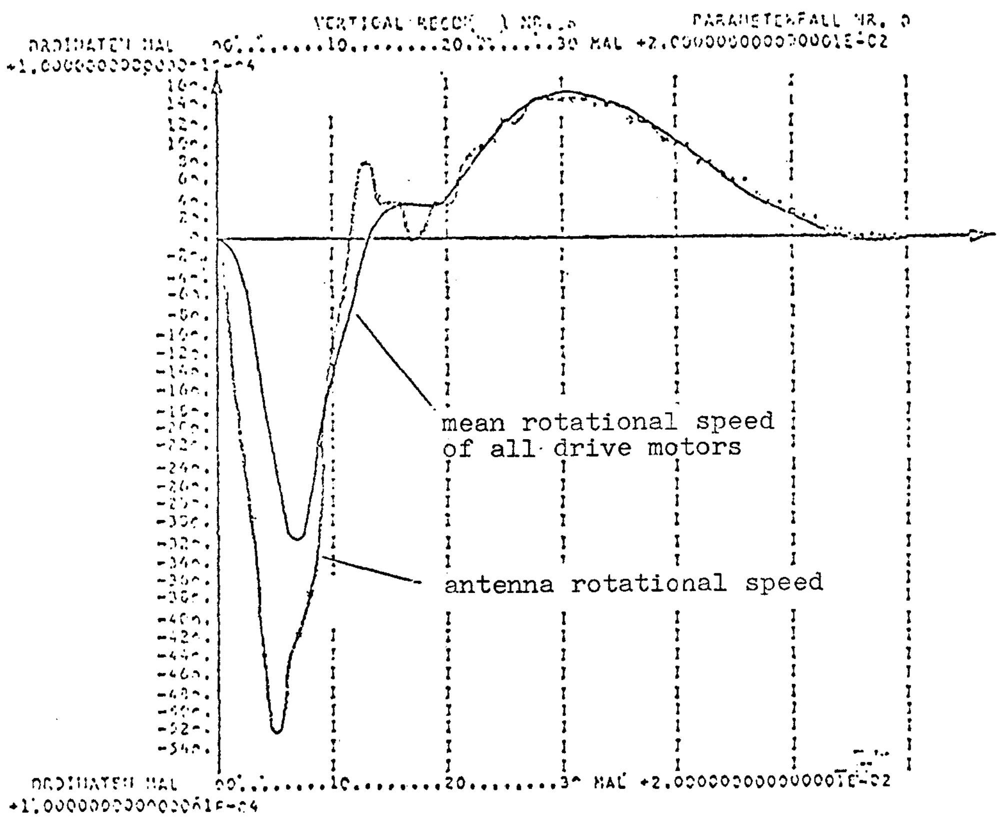

Fig. 2   Changes in antenna rotational speed and in the mean rotational speed of all drive motors resulting from compensation of a gust of wind

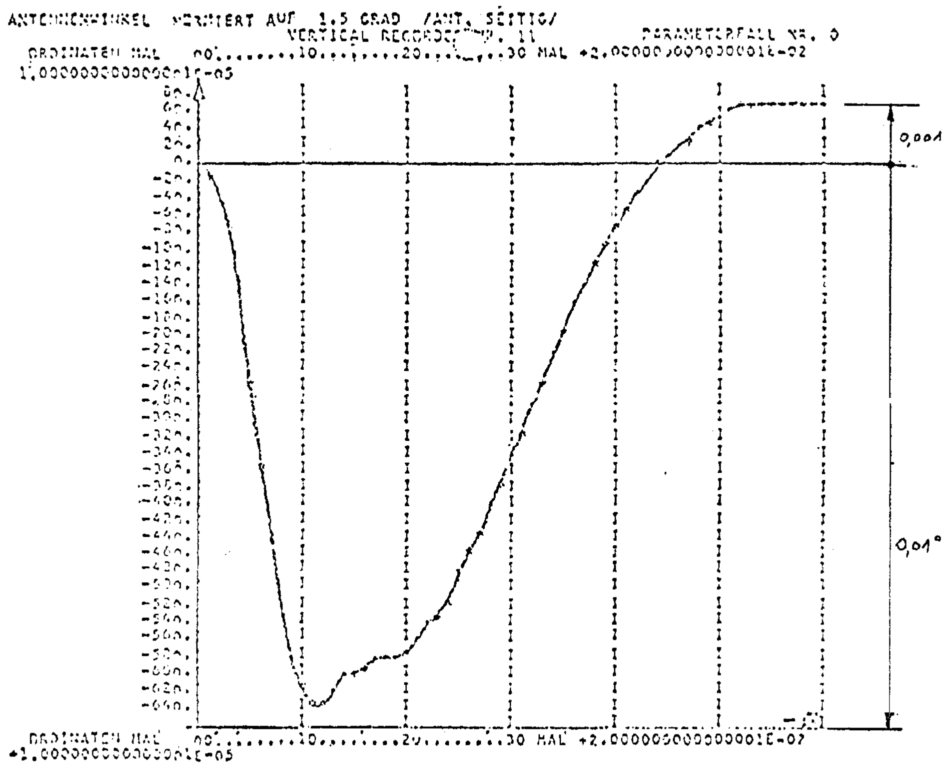

Fig. 3 Transient response to the error in angle of the antenna in compensating a gust of wind

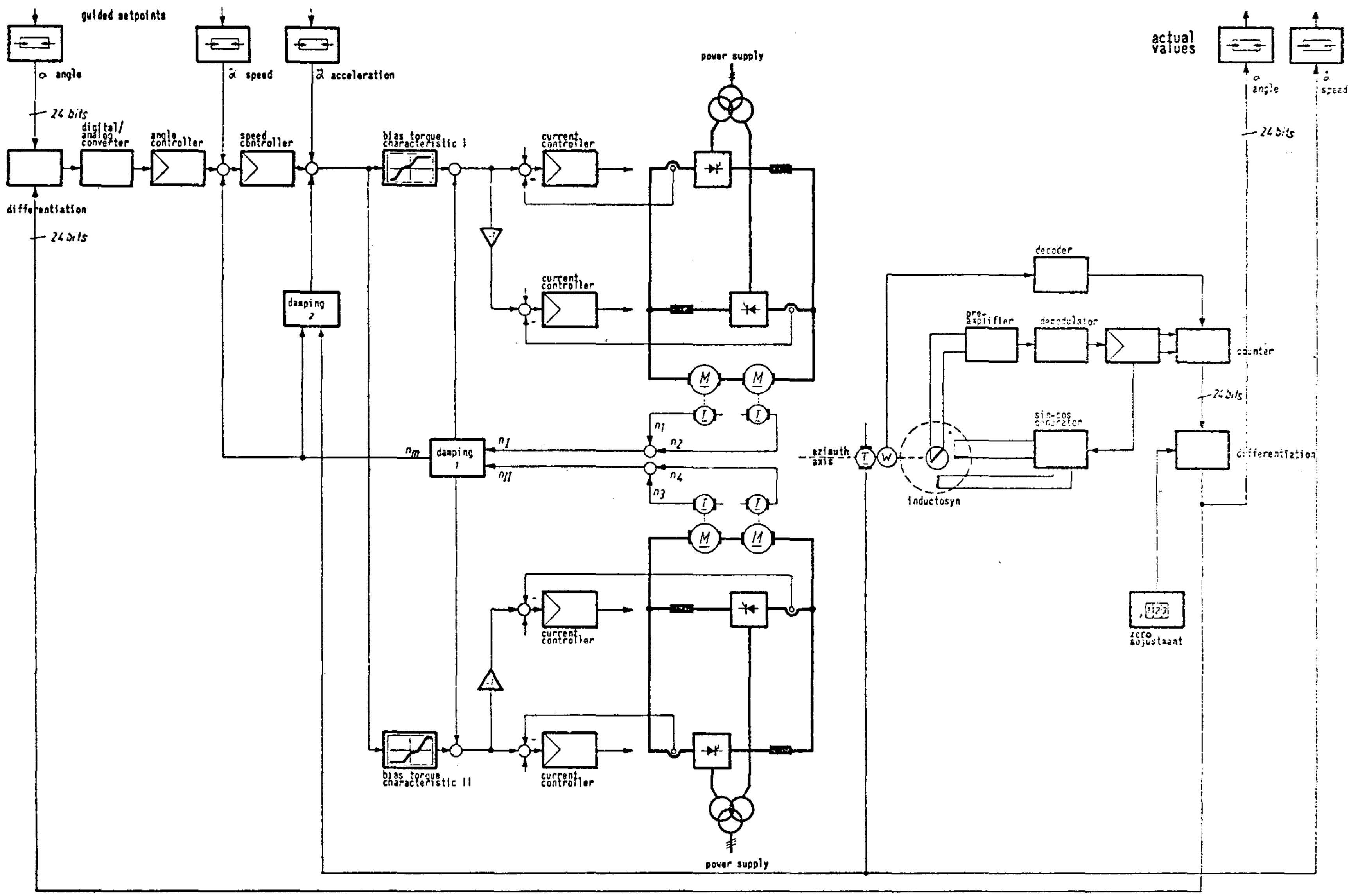

Fig. 4 Schematic diagramm of control system and actual value formation