Development of Automatic Facilities for ZEPHYR

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IPP 1/205 April 1982
Reprint of ZEPHYR-Report No. 37 of May 1981

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Abstract

This concept of remotely controlled facilities for repair and maintenance tasks inside the ZEPHYR vacuum vessel uses a supporting structure to insert various types of mobile automatic devices into the vessel. In operating position the automatic devices are guided by an egg-shaped disc which is part of the supporting structure. Considerations of adapting the guiding disc to the vessel contour are included.

Development of Automatic Facilities for ZEPHYR

In addition to universal manipulators for general-purpose remote-handling applications, special automatic facilities will be necessary owing to the space requirements and excessive time consumption of conventional handling methods. Automatic facilities are required for very specific purposes, especially for all manipulations inside the vacuum vessel (e.g. cutting and welding of the vessel, limiter and heat shield exchange, leak detection, observation).

The concept chosen for these operations makes use of a supporting structure to insert the automatic facilities through a port into the vacuum vessel and position them accurately. The supporting structure (Fig. 1) consists of a rigid supporting beam on a firm base which bears an egg-shaped disc via a second hinged arm. This disc serves as a guiding structure for the different carriages for the automatic facilities. During the insertion phase the carriages will be positioned at the front end of the guiding disc with the support arms stretched out. The possible working area at the device is sketched in Fig. 2 and allows the vessel to be cut into quadrants using only one port. To achieve adequate stability of the 7 m long supporting structure, nearly the full cross-section of the port has to be utilized for the support arm profile. The carriages will be equipped with a 4-axis wheel frame (Fig. 3) and can move around the contour of the guiding disc.

The size of the guiding disc is limited by the port and the space required for the carriage. Figure 4 shows the cross-section of the inner surface of the vessel. It is given by an egg-shaped curve symmetric to the x-axis. If we assume that it consists of 4 arcs of circles joined smoothly to each other, then M_3 (x_3, y_3) is given by

$$x_3 = -\frac{\rho_2^2 - \rho_1^2}{4e}, \qquad y_3 = -\sqrt{\rho_1^2 - (e + x_3)^2},$$

where e, ρ_1 and ρ_2 are given by

$$e = 1/2\,\overline{M_1 M_2}, \quad \rho_1 = r_3 - r_1, \quad \rho_2 = r_3 - r_2 .$$

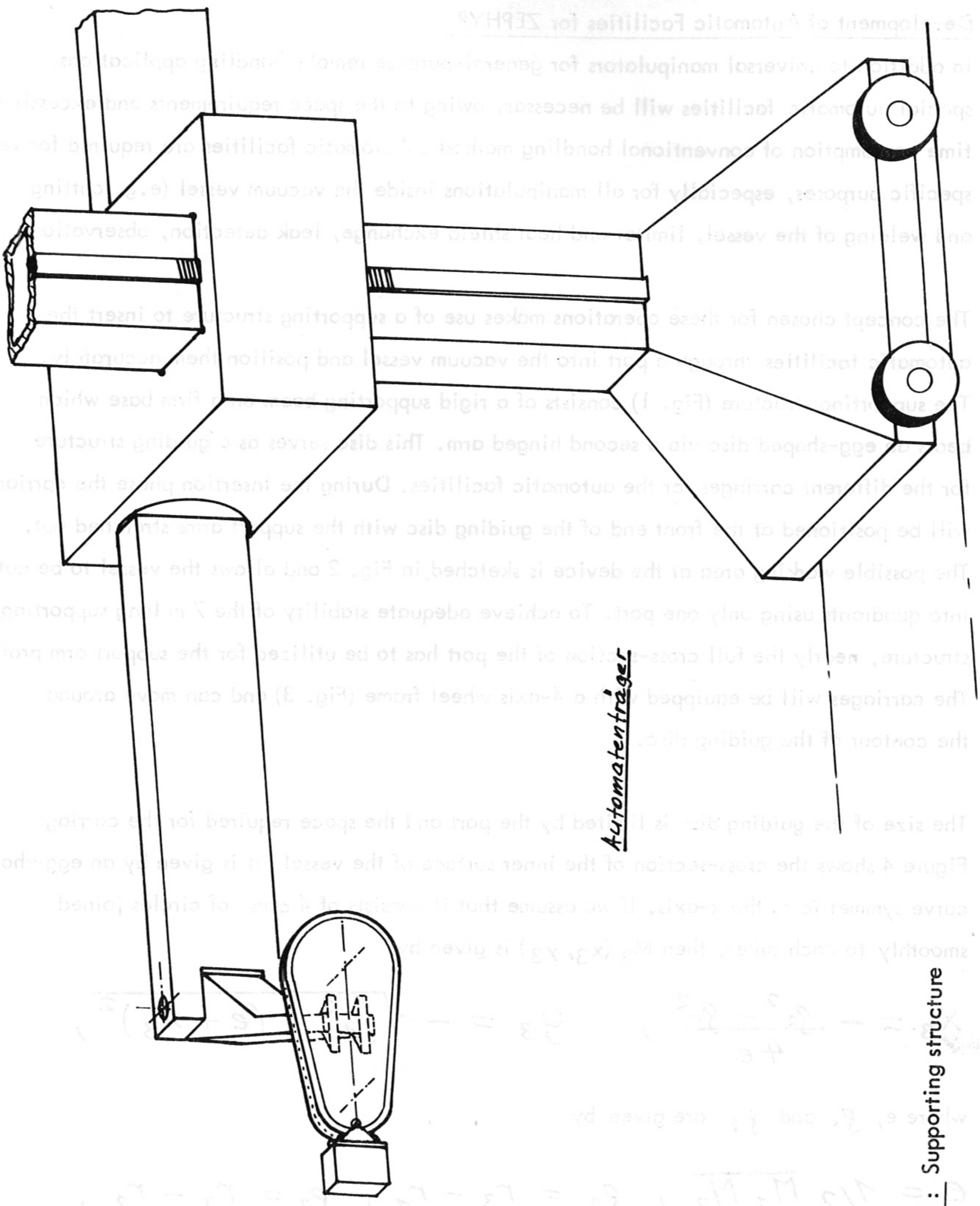

Fig. 1: Supporting structure

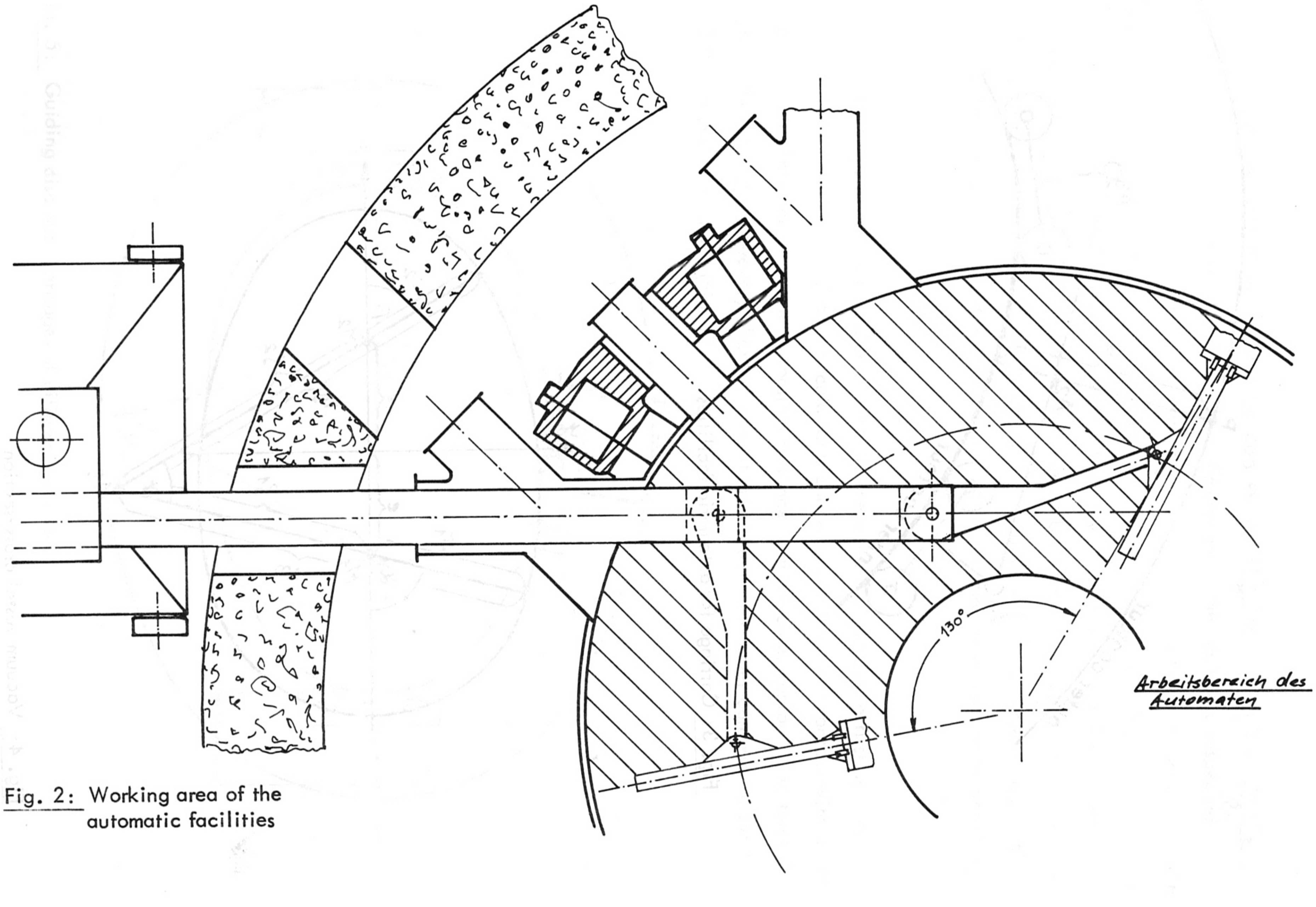

Fig. 2: Working area of the automatic facilities

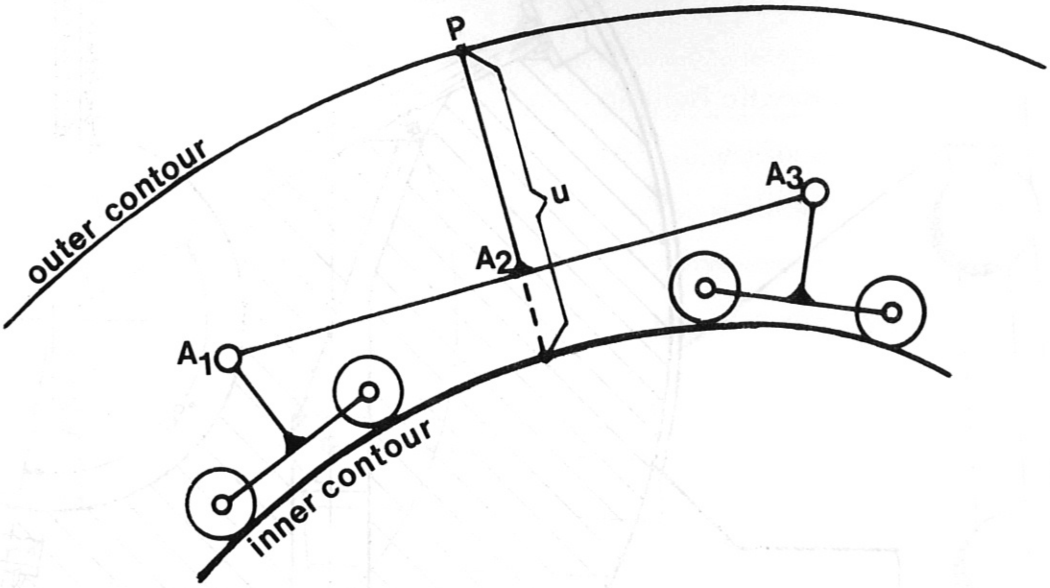

Fig. 3: Carriage for automatic facilities

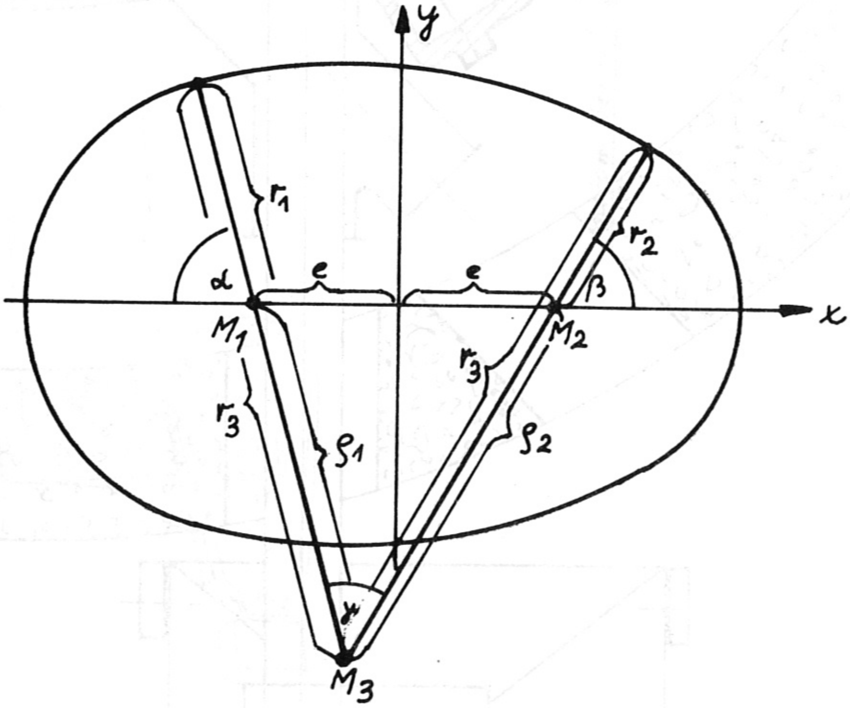

Fig. 4: Vacuum vessel cross-section

The centriangles α and ß are obtained by $\cos\alpha = \frac{e + x_3}{\varrho_1}$, $\cos\beta = \frac{e - x_3}{\varrho_2}$.
Here r_3 can be chosen arbitrarily if the given dimensions of the vessel are respected. O. Eder, who made the calculations, proposes $M_3\,(-e, -\varrho_1)$ as a suitable location for the centre M_3 of the middle arc of circle, for then α will be 90°. This will simplify production of the work piece. (The values thus obtained differ only slightly from the original ones.) The choice of $r_3 = \infty$ yields a particularly simple boundary, the cross-section of which is a straight line in the middle part. But the stability of the wall of the vessel to external forces will be reduced as opposed to a boundary with a cross-section shaped as an arc of a circle.

The shape of the guiding disc has to be adapted to the vessel contour. As a first approach, this shape was chosen to consist of 4 circular arcs concentric to the outer contour with smooth transitions. This inner contour is at a constant distance from the outer contour. The total height of the carriage, however, changes when it moves along the inner contour, owing to the different path curvatures (Fig. 5).

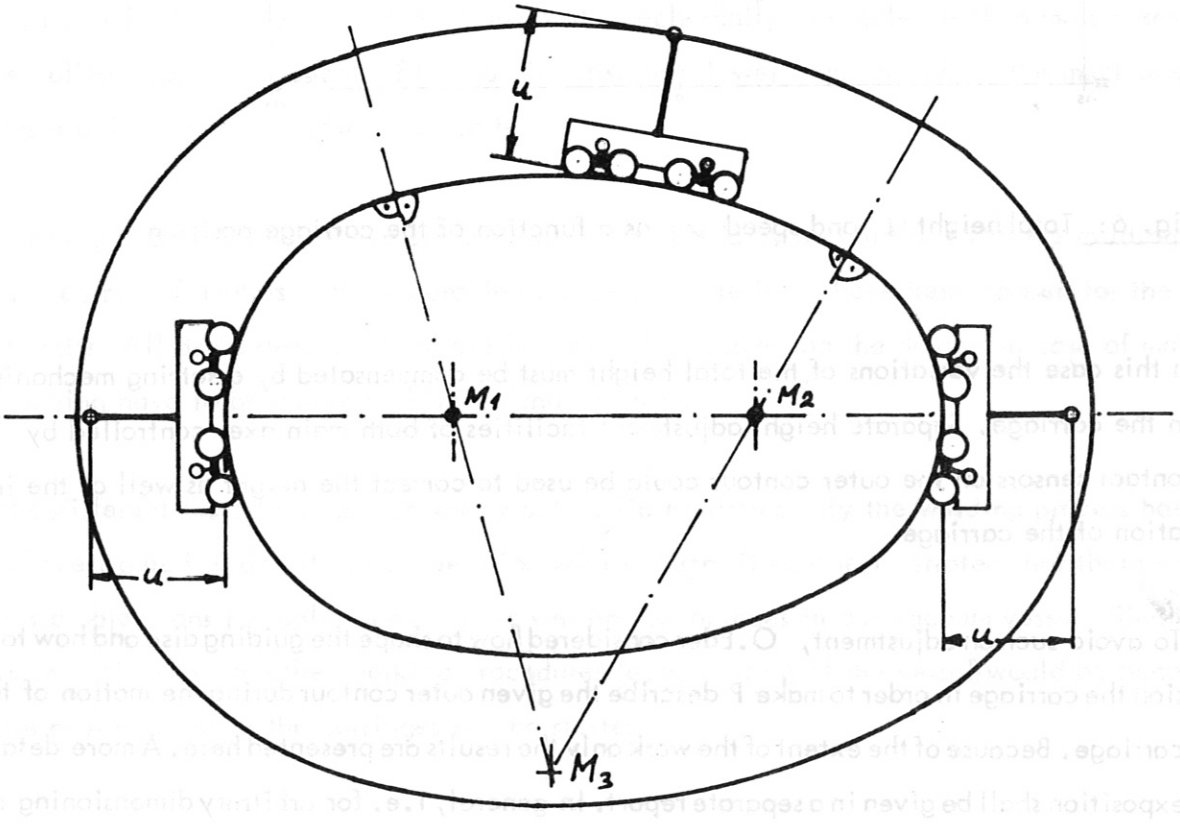

Fig. 5: Guiding disc with carriages at different positions

This variation of the height is strongly influenced by the distance of the main axes, which ought not to be made too short for mechanical reasons. On the basis of this inner contour, F. Pohl calculated the total height u and the speed v of the point P (with a given drive mechanism) as a function of the position of the carriage. The results of a sample calculation are given in Figure 6.

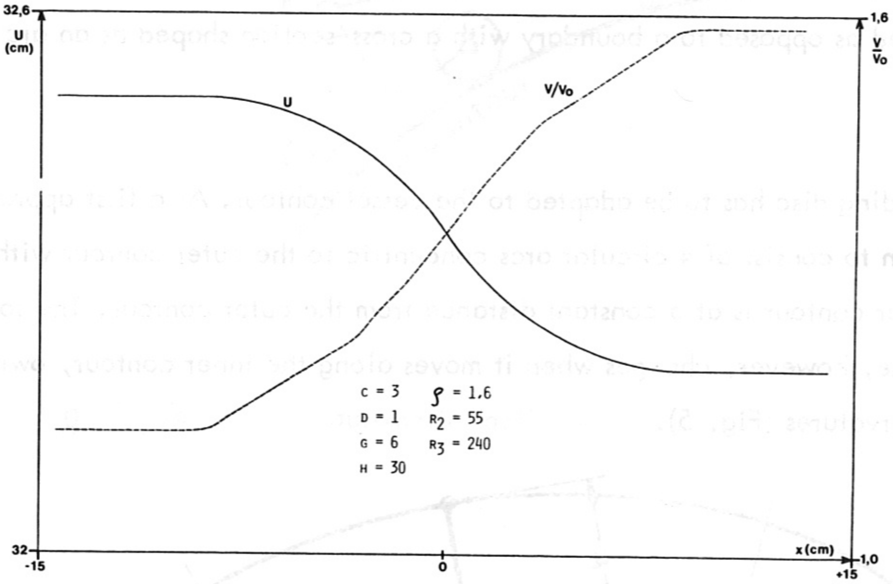

Fig. 6: Total height u and speed v as a function of the carriage position

In this case the variations of the total height must be compensated by a setting mechanism on the carriage. Separate height adjustment facilities of both main axes controlled by contact sensors on the outer contour could be used to correct the height as well as the inclination of the carriage.

To avoid such an adjustment, O. Eder considered how to shape the guiding disc and how to dimension the carriage in order to make P describe the given outer contour during the motion of the carriage. Because of the extent of the work only the results are presented here. A more detailed exposition shall be given in a separate report. In general, i.e. for arbitrary dimensioning of the vacuum vessel and of the carriage, the requirement can be exactly met by letting the wheels of the vehicle run on different rails in certain transition regions. - One possibility of realizing this is automatic setting of shunts. In this way the constant speed of P which is usually required can be achieved in the simplest possible manner. This is done by changing the driving speed of the vehicle only at the 4 transition points and letting it remain constant in the intervening domains. - There is another possibility of realization without setting of shunts that is even simpler for production. This consists in suitably profiling the front side of the guiding disc and choosing the appropriate distance between the wheels. However, there then appear very small zones in which the carriage does not move with constant speed when the driving speed is constant. This requires a control mechanism for the driving speed if an absolutely constant speed of P is required.

If we put up with certain constraints on the dimensioning of the carriage and the vacuum vessel, then a single inner contour for achieving what is required, can be given. The speed of the carriage, however, is no longer constant anywhere at constant driving speed. But it changes continuously in the whole region just like the acceleration.
Besides these exact solutions there exist some different approximate solutions. Deviations of the point P from the outer contour remain at a technically tolerable level in most cases. But simplification of the shape of the guiding disc or a lower requirement for the mechanism allows a reduction of manufacturing costs.

The carriages contain their drive systems which are linked by a chain fixed to the guiding disc. Electric DC motors with favourable control characteristics have been chosen for the drive units. All drive systems which are important for recovering the device in case of malfunctioning have to be equipped with redundant units.

Of the different tasks to be performed by automatic facilities only the welding process has been investigated in detail. In cooperation with industry it was demonstrated that there are no basic objections to applying automatic welding techniques in our vacuum vessel. Similar basic investigations of other working procedures (e.g. cutting of the vessel) would be necessary before development of the carriages can be started.

Estimated costs:

Basic price of the support structure with hinged arm	DM 210.000,--
Cutting device	DM 45.000,--
Suction unit for the cutting device	DM 70.000,--
Cabling system	DM 8.000,--
Welding device	DM 160.000,--
Observation device (TV monitor)	DM 15.000,--

Control Systems

It is planned to use two different types of positioning systems for automatic facilities. Computerized numerical control systems (CNC), which are offered by several suppliers (also by a possible manufacturer of the support structure), are best suited to meeting the high requirements for a guiding system for a fully developed and tested automatic system. These devices are able to perform different modes of operation including manual and keyboard control, repetition of motion cycles, and the execution of motion programs. Other features are automatic approach to the starting position and interpolation of path curves. Depending on the complexity envisaged, the system may be equipped with up to 6 controlled axes, displays for position coordinates, and other operational data as well as programming and editing facilities. Different kinds of peripheral devices (e.g. graphic displays) or a master computer for the coordinated control of several units may be connected. The block diagram of a possible CNC version is shown in Fig. 7.
With positioning systems of this kind it seems possible to perform all necessary tasks on a tolerable time scale. These highly developed systems have to be adapted to the characteristics of the device to be controlled. They can therefore only be applied at an advanced development and experimental stage of automatic devices. Typical problems which have to be investigated experimentally are the behaviour of different components subjected to varying forces and possible dynamic effects (overshoot, vibration).

It therefore seemed appropriate to provide another less sophisticated but more flexible positioning system for the development and test phase. For this purpose a single-axis, microcomputer-controlled positioning system has been chosen which, together with the

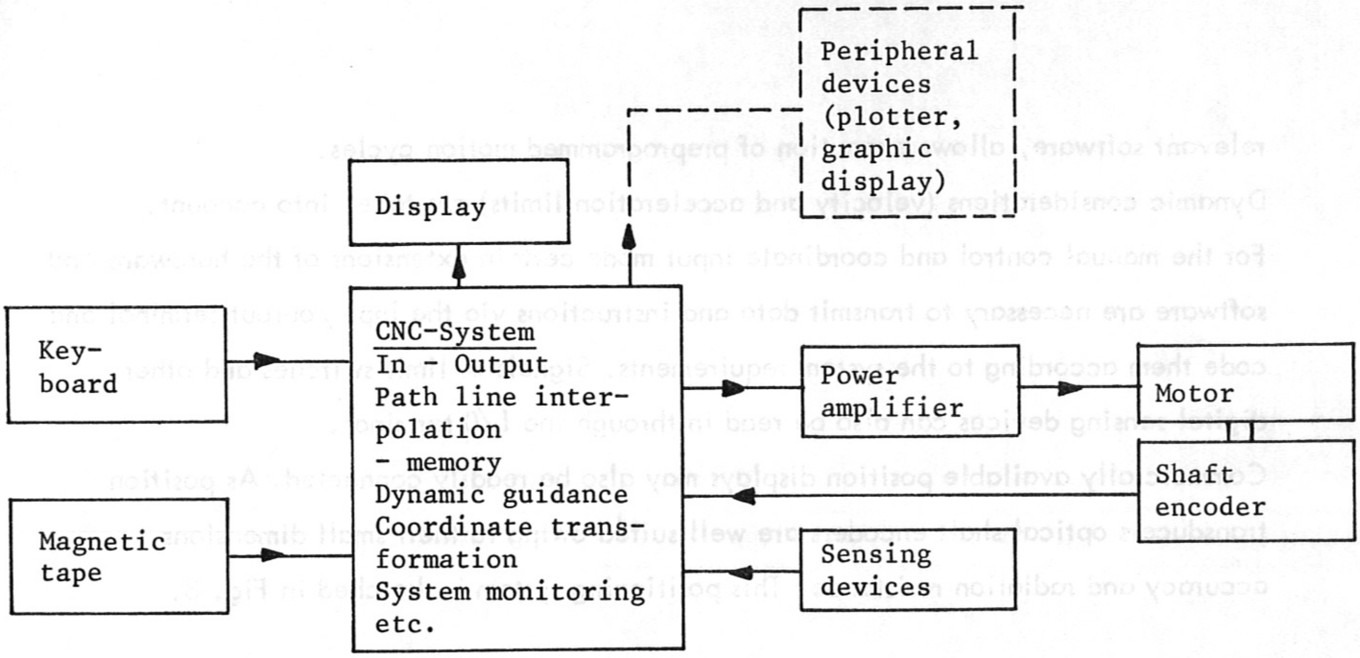

Fig. 7: Positioning system for fully developed automatic facilities

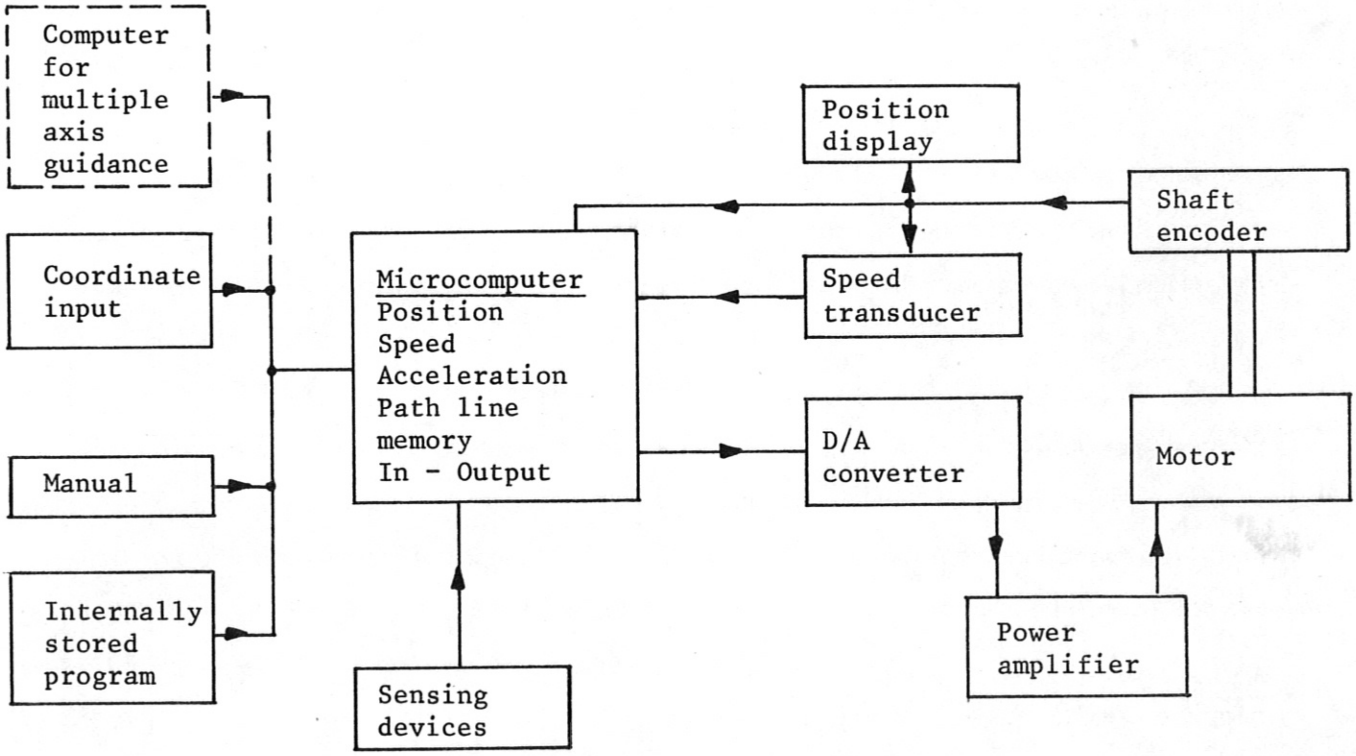

Fig. 8: Positioning system for testing of different components

relevant software, allows execution of preprogrammed motion cycles.
Dynamic considerations (velocity and acceleration limits) are taken into account.
For the manual control and coordinate input mode certain extensions of the hardware and software are necessary to transmit data and instructions via the input/output terminal and code them according to the system requirements. Signals of limit switches and other digital sensing devices can also be read in through the I/0 terminal.
Commercially available position displays may also be readily connected. As position transducers optical shaft encoders are well suited owing to their small dimensions, accuracy and radiation resistance. This positioning system is sketched in Fig. 8.

The costs of a 6-axis CNC system are estimated to be about DM 80.000,-,
a simple positioning system for the development phase about DM 6.000,- per axis.