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Manfred Dworski and Manfred Michel

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Description of the novel propulsion system for the PX-15 research bathyscaphe, using inverter-fed three-phase squirrel-cage motors. Before final assembly, the plant was tested in a test basin under simulated operating conditions. The data obtained during the tests are reported.

General

A new propulsion and control system was developed and built by AEG-TELEFUNKEN in co-operation with the PLEUGER-UNTERWASSERPUMPEN company for the PX-15 research bathyscaphe built by Dr. Piccard (Lausanne) for the Grumman Aircraft Engineering Corporation. For the electric drive system, the specification demanded that the drive motors — water-filled three-phase squirrel-cage induction motors — should be fed from a battery.

Fig. 1 shows the model of the PX-15 bathyscaphe with the laterally attached tilting drive motors. The possible uses of the PX-15 in the increasingly important field of oceanic research as well as its design and technical characteristics have already been described [1].

Propulsion system

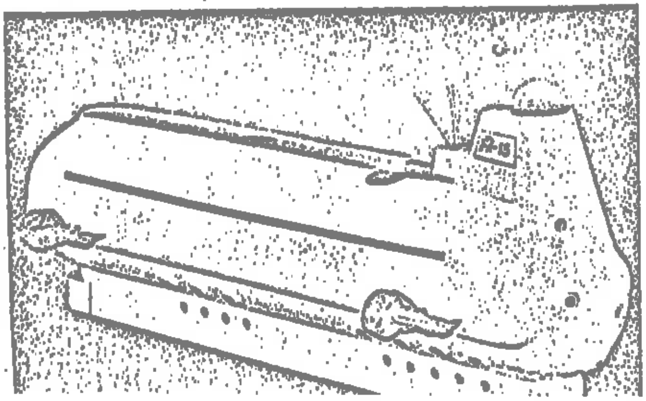
The propulsion system of the PX-15 bathyscaphe consists of four individual units. Each unit consists of a PLEUGER submersible motor and a tilting gear with an auxiliary motor. The PLEUGER submersible motors are water-filled, eight-pole squirrel-cage motors with an output of 25 PS each at 720 rpm. The water filling of the motor lubricates the soft rubber bearings, cools the winding and also serves as a support medium against the water pressure during diving.

The power source is a battery arranged in the keel of the bathyscaphe. This battery has a capacity of 2500 Ah at an average voltage of 304 volts and forms a d.c. voltage source which feeds the three-phase squirrel-cage motors via inverters. The inverters are arranged for a variable output voltage and frequency, each inverter serving two motors. The switchgear installed allows any desired inverter/motor combination.

The four motor outriggers can each be tilted through 360°. The tilting shaft is driven via a worm gear by a PLEUGER submersible motor with an output of 0.5 PS at 1700 rpm. These motors are also fed from the battery via inverters.

Fig. 2 shows the general arrangement of the propulsion and tilting motors on the PX-15 bathyscaphe as well as their electric supply system.

Fig. 3 illustrates the test bed setup of two drive units in the test basin of the PLEUGER company. In this photograph the propulsion motors are shown in the horizontal position and the tilting motors and their transmission gear in the vertical position.



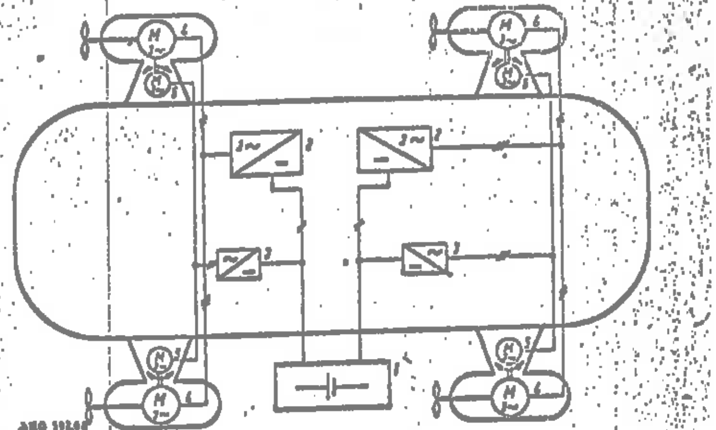


Fig. 2. Arrangement of propulsion and tilting motors together with the power supply system

1 Battery for 2500 Ah
2 Thyristor pulse inverter for propulsion motors
3 Thyristor inverter for tilting motors
4 Propulsion motors
5 Tilting motors

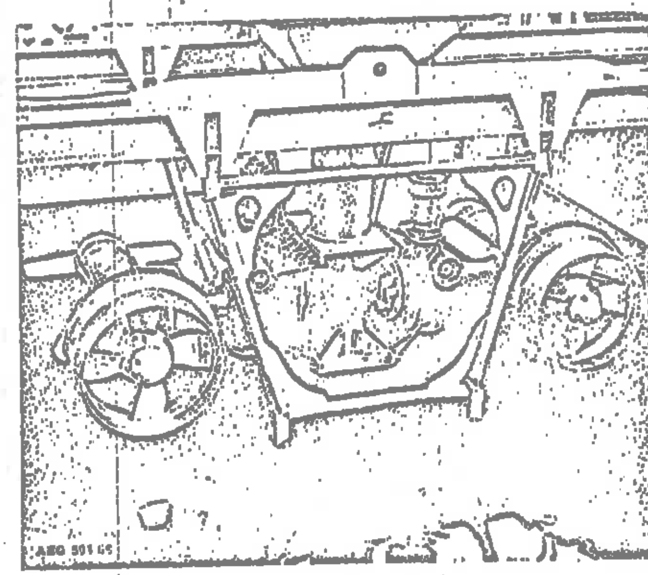


Fig. 3. Test bed installation of two drive units

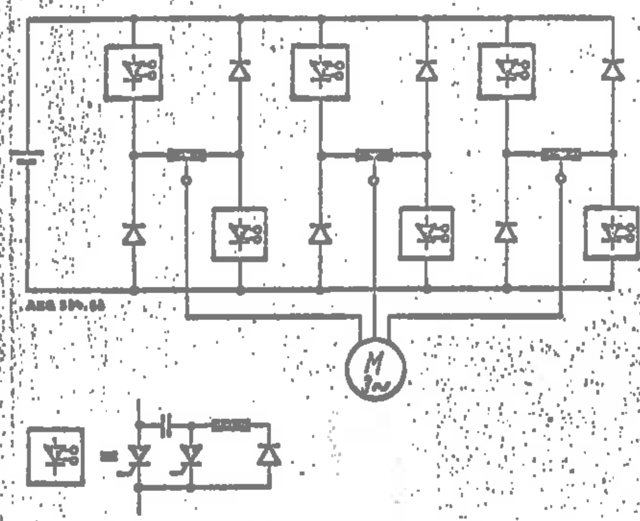


Fig. 4. Basic circuit diagram of pulse inverter
Basic circuit of turn-off thyristors

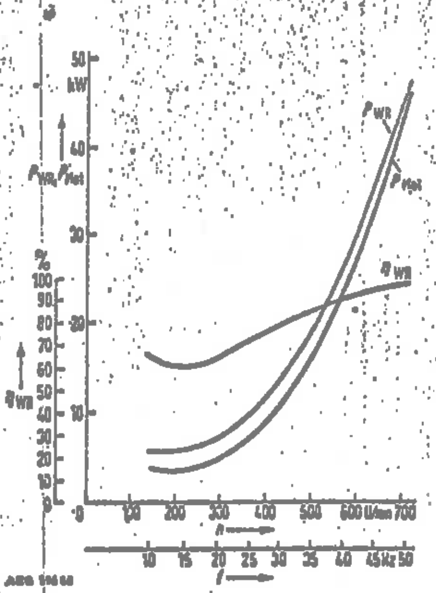


Fig. 6. Inverter efficiency η_{WR}, input power P_{WR} and output power P_{Mot} of the inverter as a function of the motor speed

U/min = rpm
Hz = c/s

to vary the output voltage of the inverter. Because of the wide speed setting range the pulse method was used for the voltage variation in the inverter.

Fig. 4 shows the basic circuit diagram of the pulse inverter used in a three-phase bridge circuit. The voltage variation by the pulse method makes it necessary that the main valves can be turned on and off at any moment. This is achieved by using thyristors which can be turned off by means of a capacitor circuit. In addition to the capacitor, this requires an auxiliary thyristor, a diode and a choke. Fig. 4 also shows the complete turn-off circuit. The advantage of voltage variation by the pulse method as compared with delayed commutation resides in the fact that the output voltage contains no additional harmonics even at a considerably reduced voltage.

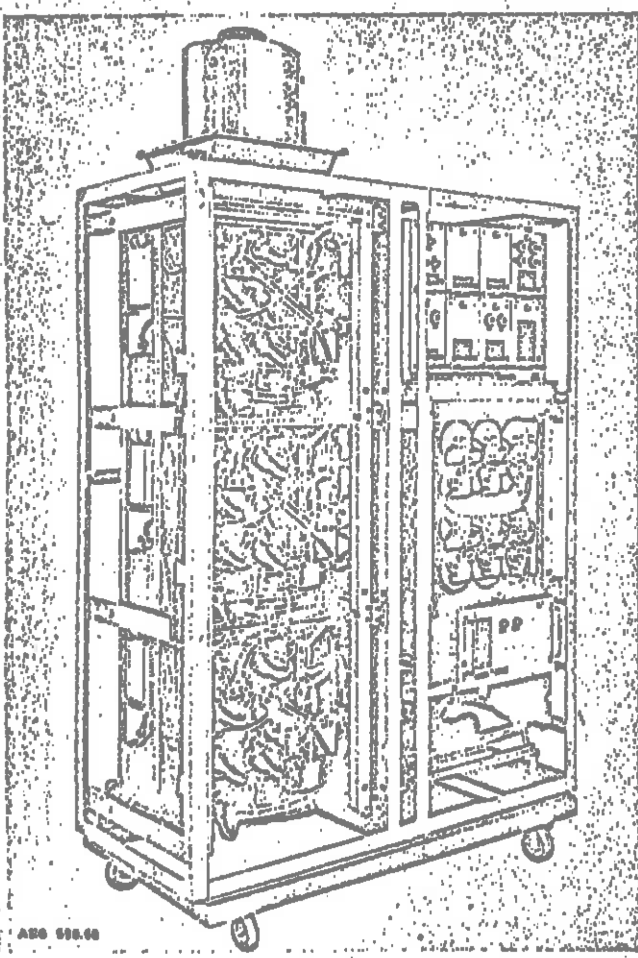


Fig. 5. Pulse inverter feeding two 25 PS PLEUGER motors for the propulsion of the PX-15 research bathyscaphe
Output power: 60 kVA
Output voltage: 220 V (three-phase) at 50 c/s;
Frequency adjustable from 0 to ±50 c/s

The speed of the motors is varied by the variable frequency of the inverter. This principle of frequency control solves the problem of speed adjustment for the propulsion drive without a tachogenerator. An electronic limit-value device prevents the motor slip from becoming excessive. The motor voltage is adjusted by a control circuit specially provided for the purpose. To improve the shape of the motor current curve, the voltage regulator operates with infraposed current regulation.

The control principle outlined above can be used for the propulsion motors of the PX-15 bathyscaphe since no impact loads can occur. In additjea, only a limited rate of speed variation is required of the drive in the case of sudden changes in the reference value. The above control principle allows reversal of the direction of rotation and feed-back to the battery during manœuvring.

Fig. 5 shows a pulse inverter for two propulsion motors. The left-hand side of the frame contains the three bridge arms of the inverter with the top-mounted fan. The bridge arms are of tray-mounted unit construction. In addition to the thyristors, they contain the fuses, the pulse transformers, the R-C elements for the thyristors and the commutating elements. On the right-hand side, the frame contains the inverter control equipment in the upper plug-in unit, while the filter elements and auxiliary equipment are accommodated in the lower plug-in units.

Trial operation of the propulsion unit and control equipment in the test basin

An inverter and two PLEUGER submersible motors were used to test the equipment and to carry out a number of studies, such as determination of the load characteristics for efficiency calculation, verification of the control response of the drive, etc. Fig. 6 shows one result of these measurements. The power input and the power output of the inverter were measured as a function of the speed, using two motors. Depending on the propeller load on the two motors, the power delivered increases approximately with the third power of the speed.

The plotting of the inverter efficiency determined from the values P_{Mot} and P_{WR} takes into account the fan losses and the power consumed by the control system. At maximum propeller speed the inverter efficiency is 95 %.

This very satisfactory efficiency at full load and the favourable behaviour under partial load, combined with the low weight of the electrical equipment for the propulsion motors, represent a valuable contribution to the effort of giving t PX-15 bathyscaphe the largest possible radius of action.

Bibliography

[1] V. Sundaran: Forschungstauchboot PX-15. AEG-Mitt. 57 (1967) pp. 125—127.