Abstract

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During the last ten years there has been an increasing interest in the research on autopilots for ships. The introduction of sluggishly reacting VLCC's which are, especially manually, difficult to steer, and the rising fuel prices, in particular, have stimulated this research. Small and inexpensive digital computers enable practical application of modern, optimal and adaptive control strategies.

A relatively simple mathematical model of the ship's steering dynamics is a basis for the design of an adaptive autopilot. Comparison with other models which are described in the literature shows that this model, despite its simplicity, gives a good description of a number of phenomena. Besides, attention has to be paid to the disturbances which influence the steering behaviour, such as wind and waves.

For optimization of the steering performance not only a mathematical model but also a performance criterion is necessary.

Two different steering modes can be distinguished: course changing and course keeping.

During course changing it appears to be desirable to turn to the new heading with a constant rate of turn, or possibly with a constant turning radius. The new heading should be reached without overshoot. The possibility to adjust the rate of turn is the only setting required by the user.

During course keeping sometimes very accurate steering is required, for instance, in re-stricted waters. However, usually the steering accuracy itself is not important, but rather minimization of the loss of speed due to steering. For the latter minimization the course error plays a role as well. A simple quadratic criterion can be derived to measure the steering losses. Besides optimization of the controller gains, suppression of fast rudder motions is essential because they have hardly any positive effect on the steering behaviour. They only cause extra drag and wear of the steering machine. The optimization pro-cedure is not only based on purely technical and economical factors but on the preferences of the users as well. An inquiry among officers of the Royal Netherlands Navy and the merchant marine has provided insight into their wishes. One setting, the selection between accurate and economical steering, appears sufficient for the users during course keeping.

Present autopilots require adjustment of two or three parameters of a PID controller, as well as adjustment of a limiter and a dead band in order to obtain the required steering behaviour under changing circumstances. The number of settings is too large and these settings do not bear a clear relation to the above-mentioned requirements of the user. Therefore, the controller settings themselves should be automatically adjusted by means of an adaptive controller.

The automatic adaptation of the autopilot described is mainly based on the theory of model-reference adaptive systems (MRAS). From the basic theory, structures are derived which realize an optimal performance under varying circumstances. During course chang-ing MRAS can be applied to direct adaptation of the controller gains. During course keep-ing MRAS is applied to identification of the parameters of a mathematical model which can be used to compute optimal controller gains. It appears that the problem of suppress-ing high-frequency rudder motions can be solved simultaneously in an elegant manner. The controller gains are not only adjusted by means of MRAS, but for variations in the ship's speed, by gain scheduling as well.

The adaptive autopilot designed was tested by means of a great number of experiments with a simulation set-up, various full-scale trials with three different ships, and a series of scale-model tests in a towing tank. During the experiments the main emphasis was put on the fuel-saving potential of the adaptive autopilot. The full-scale trials, with sea states between 2 and 4, indicate possible fuel savings between 0.5 percent, for following seas, and 3 percent for head seas, compared with a well-adjusted conventional autopilot. During the model tests, in higher sea states (5 to 7), even higher savings were found.