Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2017, 49 (121), 59–62
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/201

Received: 07.11.2016
Accepted: 13.02.2017
Published: 17.03.2017

On the possibility of ship's steering gear load monitoring by observing the number of reversals in a specific time

Andrzej Stefanowski

Maritime University of Szczecin, Department of Automation and Robotics
1–2 Wały Chrobrego St., 70-500 Szczecin, Poland, e-mail: a.stefanowski@am.szczecin.pl

Key words: automatic control, steering the ship, steering gear of a vessel, load of steering gear, rough sea conditions

Abstract
This article presents the problem of overloading of the steering gear controlled by an autopilot in high sea states and ways of reducing it. The author proposes a new method of estimating the steering gear load by counting the number of machine reversals in a selected time period. A block diagram of such solution is presented along with the results of simulations of system operation in different sea states. The results obtained, in terms of number of reversals, depend significantly on the state of sea, providing a means to estimate the current state of the sea as well as the expected difficulty in exploiting the steering gear.

Introduction

The navigational safety of a ship, which also translates into the safety of people, cargo, and other participants of the water transport system, depends on the reliable operation of the ship's steering gear. The construction of the power systems of the steering gear may generate a different torque on the rudder stock (e.g. mechanical, electro-mechanical, electro-hydraulic-mechanical transmissions).

The chosen method of torque generation depends on its designed value for a given vessel.

Steering gears are designed and built taking into consideration these factors:
- size and type of rudder;
- ship's speed;
- changes in torque on the rudder stock (as a function of angle of rotation of the stock shaft);
- assumed rate of rudder movement at 'full ahead';
- generation of the assumed torques at 'astern' speed;
- achievement of the assumed mechanical and thermal strengths under dynamic loads, resulting from the long rudder movement from one side to the other with the appropriate frequency and amplitude.

These devices are subject to special supervision by classification societies (e.g. Polish Register of Shipping, Lloyd's Register, Det Norske Veritas GL, Russian Maritime Register of Shipping), which are aimed at verifying the fulfilment of material, construction, power supply, control and performance requirements. Additional requirements specify the methods of power supply, type of alarm signals, and static accuracy.

During automatic operation of the vessel in high sea states by means of the autopilot, designed values are exceeded (especially temperatures of devices and the working medium, currents of main electric motors and actuators), leading to power overload of the device.

Insufficient power of steering gear installed on ships results from economic reasons. The periods in which the steering gear works in high sea states (6–9) constitutes about 20–30% of the ship's service life (Waguszczienko & Cymbał, 2002). The remaining 70–80% of the lifetime falls to low and medium sea states (good weather conditions), in which the steering gear operates under a small or very small load (e.g. up to sea state 3 the average amplitude of rudder deflections does not exceed 5 degrees, i.e., approx. 16% of the designed amplitude – 30 degrees).

Installing a more powerful machine is therefore not advisable from the economic viewpoint. In addition, when working at lower sea state a higher power of the steering gear would reduce the so called course stability of the ship, which in turn increases the ship dragging forces, decreases its average speed and, consequently, raises operating costs due to increased fuel consumption.

Therefore it is typical for the steering gear to be overloaded during operation under rough sea conditions while the autopilot is on.

For this reason it is necessary to appropriately monitor the situation and take measures to reduce the load (at the expense of lower course-keeping quality). A ship's steering gear should be carefully protected against damage. It is recommended that physical quantities that may be exceeded should be continuously monitored and an alarm signal should be activated in case their values are actually exceeded (Stefanowski, 2010; Stefanowski & Zwierzewicz, 2012). The regulations of classification societies (PRS, 2007) require steering gear overload signaling, which most often takes place when the average current of electric motors driving hydraulic pumps is exceeded in relation to the rated current, or when the permissible temperature of the hydraulic working medium rises above the limit. Alarm signaling should make the deck and engine personnel reduce the mechanical load. Reducing the load of the steering gear can be achieved by reducing the rate of rudder movement and/or the amplitude of rudder deflections, filtrating higher harmonics in the rudder deflection set point, or introducing a dead zone in the proportional path of the course controller (Wyszkowski, 1982). In Stefanowski (Stefanowski, 2013) it was proposed to reduce the load by decreasing the angular speed of the rudder. Alarm signaling of the steering gear overload does not affect the load, but knowledge that the load is tending towards its maximum permissible value may allow taking measures to relieve the steering gear even before the alarm is raised. This could lead to better use of the autopilot in high sea states by avoiding the need to turn off overheated devices to let them cool down. The steering gear load (average power is not measured) can be estimated on the basis of rudder deflection signal analysis. In Stefanowski (Stefanowski, 2011) the author proposed for this purpose a special algorithm implemented by a function block.

This paper proposes to estimate the steering gear load based on the number of reversals in a specific period of time. The practice of steering gear operation shows that as the sea state increases, the number of reversals also increases, and consequently, steering gear load rises, reaching the maximum alarm level in sea state 7 or 8.

The proposed solution

Figure 1 shows the proposed technical solution in the form of a block diagram of rudder angle signal acquisition, its conversion to decimal counter

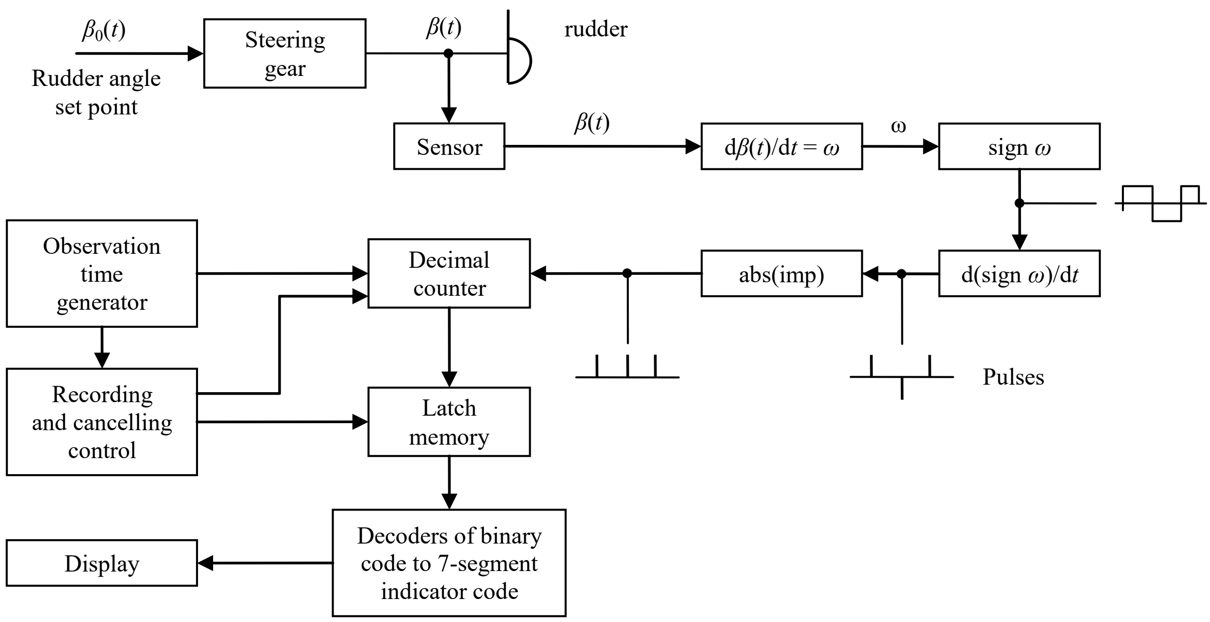

Figure 1. The block diagram of the steering gear reversals counter (reversal is defined as a change in direction of rudder movement)

control of the number of steering gear reversals and the display of reversals counted within a specific period of time.

When the rudder angle signal is received from the rudder angle sensor, the angular velocity ω of the rudder is calculated by the differentiation of that signal by the real system with a low time constant. After the angular velocity signal is received, the signal sign is determined as a function of time in the form of a zero-one signal. The differentiation of the signal as described above gives a series of positive and negative pulses. Each pulse represents a change in the direction of rudder movement. To obtain pulses of one polarity, necessary for the control of the decimal counter, the signal is passed through a rectifier defining positive values of pulses with negative polarity.

The number of pulses (indicating the number of reversals) is counted for the time specified in the square-wave signal generator – observation (counting) time. The period of this generator is slightly longer than the observation time. The observation period, for example 30 minutes, is approximately 99.9% of the generator period. After a period of observation, the decimal counter is stopped and its contents are copied to the latch-type memory. After saving the counter state in the latch memory, the counter is reset to zero and the generator of observation time unlocks the counting of subsequent pulses.

Once placed in the memory latch, the coded number of pulses is converted by binary code decoders into a code of seven segment indicators for its presentation in the decimal system. The value indicated by the display persists until the next entry in the memory latch, which will take place after the next observation period. The crew should be familiar with the permissible number of reversals of the steering gear installed on their ship. This is the number of reversals that will occur when the alarm signal is sent due to overloading the steering gear controlled by the autopilot in case no gear load limits are introduced.

A fixed number of reversals of the steering gear at a particular time can also be used to start an alarm in the event this number exceeds the limit number of reversals (programmed by the crew). The proposed system must then be extended with additional units

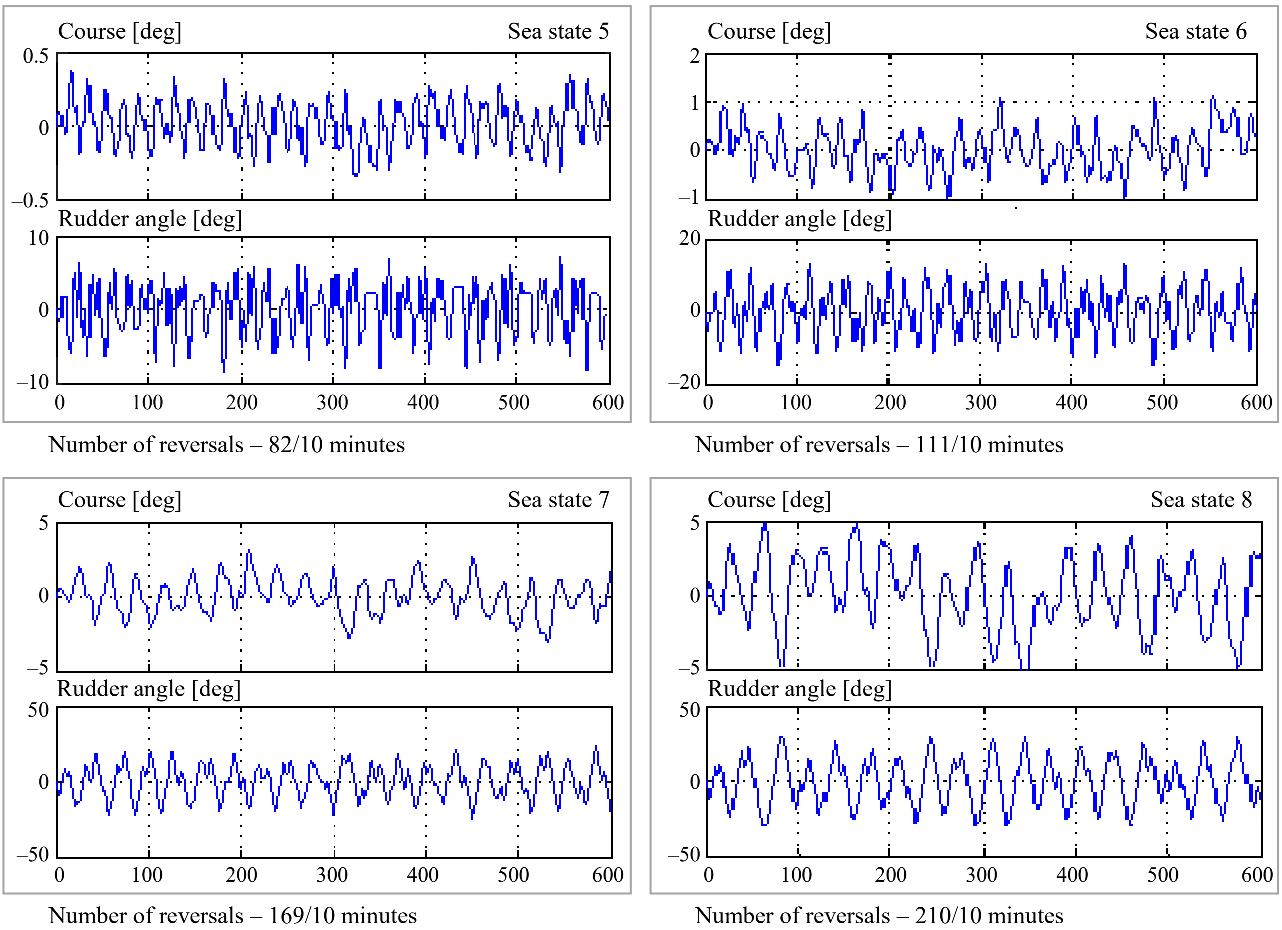

Figure 2. The simulation results of the ship course stabilization system for various sea states and the observed number of steering gear (rudder) reversals

(programmable digital set point adjuster, comparator and control system).

The results of simulation studies

To evaluate the possibility of identifying the number of rudder reversals in a time unit on the basis of the proposed solution, a course stability system was modeled (MATLAB-Simulink) by adopting a simplified linear model of a ship's dynamics of the NOMOTO type (Lisowski, 1981) and a simplified model of the steering gear with constant delivery pump (Stefanowski, 2006). Disturbances acting on the hull were modeled for a given sea state applying method described in (Kochenburger, 1975), which uses the random function of time with the spectral density of sea wave power written as:

$$S(\omega)=\frac{2Dr\alpha\left(\alpha^2+\beta^2+\omega^2\right)}{\omega^4+2\left(\alpha^2-\beta^2\right)\omega^2+\left(\alpha^2+\beta^2\right)^2} \quad (1)$$

where:
β – the resonant frequency of spectrum, $\alpha = 0.21\beta$,
Dr – process dispersion.

The PID course controller was tuned to 10% overshoot of the introduced set course correction. The conversion of the wave ordinate into the ordinate of torque acting on the vessel was chosen experimentally so as to obtain ship course alterations in the range of those encountered in practice at different sea states.

Figure 2 shows the results of the simulation, presenting the course of the vessel and, rudder deflection angle in degrees and the counted number of rudder reversals over 10 minutes of observation.

Conclusions

Based on the simulation results we can state that the number of rudder reversals increases with the sea state and that figure, even in a relatively short period of observation of 10 minutes differs significantly for different sea states (from approx. 30 to approx. 60), which proves that changes in the number of reversals along with the increase in sea state are large. An indication of the reversal number makes it possible, for the engine crew in particular, to assess the current state of the sea and the difficulties in the operation of the steering gear itself due to its load. Consequently, based on this information the engine personnel may make decisions towards the reduction of the number of reversals if it exceeds the allowable limit. Such a reduction may be attained, for example, by a change of course regulator gain or of rudder angular speed.

The presented method of converting the rudder angle signal for the purpose of counting the number of reversals did not cause any problems in the operation of the course stabilization model. It can be assumed that the proposed solution can be applied in practice.

References

1. Kochenburger, R.J. (1975) *Modelowanie układów dynamicznych przy użyciu maszyn matematycznych.* Warszawa: Wydawnictwo Naukowo-Techniczne.
2. Lisowski, J. (1981) *Statek jako obiekt sterowania automatycznego*. Gdańsk: Wydawnictwo Morskie.
3. PRS (2007) Przepisy Polskiego Rejestru Statków. Wydawnictwo PRS.
4. Stefanowski, A. (2006) Koncepcje sterowania elektrohydrauliczną maszyną sterową statku z pompą o stałej wydajności zwiększającego dokładność statyczną układu. *Zeszyty Naukowe Akademii Morskiej w Szczecinie* 10 (82). pp. 355–367.
5. Stefanowski, A. (2011) *Ocena warunków pracy maszyny sterowej statku na podstawie sygnału bloku funkcyjnego*. Proceedings of the XIV International scientific and technical conference on marine traffic engineering. Maritime University of Szczecin, pp. 459–467.
6. Stefanowski, A. (2010) *Monitorowanie obciążenia elektrohydraulicznych maszyn sterowych statków.* Nadieżnost i Effektiwnost Techniczeskich Sistiem – mieżdunarodnyj sbornik naucznych trudow. Kaliningrad: KGTU.
7. Stefanowski, A. (2013) Reduction of ship steering gear load at high sea states by decreasing ruder angular velocity. *Scientific Journals of the Maritime University of Szczecin* 36 (108) z. 1. pp. 138–143.
8. Stefanowski, A. & Zwierzewicz, Z. (2012) Assessment of ship steering gear load based on an analysis of rudder angle signal. *Scientific Journals Maritime University of Szczecin* 30 (102). pp. 126–131.
9. Waguszczienko, L.L. & Cymbał, N.N. (2002) *Sistiemy awtomaticzeskogo uprawlienia dwiżeniem sudna.* Odessa: Łatstar.
10. Wyszkowski, S. (1982) *Autopiloty okrętowe*. Gdańsk: Wydawnictwo Morskie.