MODELLING OF MANEUVERING OF THE SHIP EQUIPPED WITH TWO AZIPODS

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Introduction

- Development of Northern Sea Route
- Vessels with stronger hulls of ice class
- New type of propulsion devices - azipods
Azipods
Mathematical modelling of work of azipods

- Hull is described by model of shifts
- Work of every azipod – by Hoffmann algorithm
- Value of propulsion force – by Lammeren curve
Essence of modelling

- Calculations are based on approximation of curves given in reference book by A. D. Hoffmann
- Arbitrary maneuvering of the ship with acquisition of all the features
  - Kinematic ones (linear and angular velocity)
  - Force ones (forces and moments)
- Results are presented as a set of graphs and conclusions
Modelling is performed with software package

The maneuvering is an interactive part of the program

Visual Basic 6 and MathCad
Algorithmization of the calculations

- For one azipod - Hoffmann algorithm

- For two azipods - Hoffmann algorithm is repeated twice

- This method allows to take into consideration the influence of one azipod on another
Algorithmization of the calculations

- Joystick for each azipod to operate actual power of the screw and angle of azipod rotation

- Power is converted into revolutions of screw

- Three differential equations of motion of model of the vessel are joined by two differential equations of screw rotation in liquid medium with accounting of moment of inertia of added masses of the ship
Software package

Convenient graphical interface, which allows to:

- choose size of the water area
- the initial position of the vessel
- afterwards launch the trial program for every vessel

Actions of ‘navigator’:

- controlling of the propulsion device by defining the actual power
- turning azipods at arbitrary angles to the diametral plane of the ship
Azipod control unit

Trajectory of the ship

Azipod working

Azipod not working
Differential equations of the task

- Task is defined by system of 5 differential equations of first order

- Three first equations define the movement of the vessel

- Those three equations will formally not undergo changes, only ‘rudder’ forces will have different meaning
Equations of the movement of the vessel

\[
\begin{align*}
(m_{11}) \left( \frac{d\nu_x}{dt} \right) &= -(m_{22}) \nu_y \omega + \left[ \frac{C_{x3} - C_{x0}}{2} v_x^2 - \frac{C_{x3} - C_{x0}}{2} vv_x + b_1 v_y^2 + 2 b_2 \frac{v_x v_y^4}{v^3} \right] \frac{\rho A_{L\sigma}}{2} + \\
C_{AX} \frac{\rho_a A_{VB} v_K^2}{2} - F_{rX} + T_E + F_X; \\
(m_{22}) \left( \frac{d\nu_y}{dt} \right) &= -(m_{11}) \nu_x \omega - \left[ 2 C_{y\beta} \frac{v_x^2 v_y}{v} + c_2 \left| v_y \right| v_y - 16 c_3 \left| v_y \right| v_y^3 v_x^4 \right] \frac{\rho A_{L\sigma}}{2} + \\
C_{AY} \frac{\rho_a A_{VL} v_K^2}{2} + F_{rY} + F_Y \\
(J_{z66}) \frac{d\omega}{dt} &= -[2 m_1 v_x v_y + m_2 vv_y + m_3 \frac{v_y v_x^3}{v^4} - 16 m_4 \frac{v_y v_y^3 v_x^4}{v^6} + C_{M0} L^2 \omega |\omega| + \\
C_{M\omega} (v^2 + L^2 \omega^2) \sin(\pi \Omega) / \pi] \frac{\rho A_{L\sigma}}{2} + C_{AM} \frac{\rho_a A_{VL} L v_K^2}{2} + M_r + M_z
\end{align*}
\]
Differential equations of the task

- Two equations left are the equations of screw rotation in liquid medium

- Different setup values of power and revolution for account of control

- First equation defines increment of screw revolution in variable conditions of movement
Equation of screw rotation in liquid medium

\[ dNs = \frac{(ccc \cdot Mdv - MyScrew.q)}{JJ}, \]

- where \( MyScrew.q \) – resisting moment of the screw in liquid medium,
- \( JJ \) – moment of inertia of the screw accounting added moment of inertia of water,
- \( Mdv \) – moment developed by electric motor of azipod:
  \[ Mdv = aa \cdot sgn(MyScrew.ns) \cdot MyScrew.ns^2 + bb \cdot (MyUst.ns - MyScrew.ns) \]

- Differential equation of operation of the second azipod screw is absolutely similar
Integration of equation system

- Differential equations are solved by Euler method
- No need to use method of Runge-Kutta
- Results of solution of the differential equations in format of increments to motion parameters are just added to previous values
- All other variables of the problem are recalculated for new values of motion parameters in every cycle of the solution
Integration of equation system

- Algorithm of Hoffmann A.D. is used for defining longitudinal and transversal forces $Fr_X$, $Fr_Y$ and torque moment $Mr$ for every azipod.

- Advance of a propeller is calculated by formula:
  \[
  J = (1 - wt)V/(ns*D),
  \]
  where $D$ – diameter of azipod screw, $wt$ – coefficient of following current.
Integration of equation system

- Coefficients of thrust $kT$ and moment $kQ$ of the screw are calculated by versatile action curves of the propeller by Lammeren, which is our main change in Hoffmann algorithm.

- Values of thrust and moment for axial accumulation of current on blades of the screw:
  - $T_0 = kT r n_2 D_4$, $Q_0 = kQ r n_2 D_5$

- The coefficient of thrust stress for axial accumulation:
  - $sT = (8kT)/(pJ2)$. 
Integration of equation system

- Rotating of the azipod leads to change of kinematic and force parameters.
- Hoffmann algorithm takes this rotation into account with the help of diagrams for coefficients $q_R$ and angle $q$ of deviation of resultant force vector of azipod from its axis.
- Both parameters depend on relative screw twist $P/D$, but we deal with curves which describe relations when $P/D = 1$. 
Integration of equation system

- For entering these functions we should determine the angle of accumulation $Y$, which is defined as difference between the angle of azipod turn $d$ and local drift angle $b_m^*$. Local drift angle without taking hull into account is defined with the help of tangent by formula:

  $$
tg(b_m) = (V_y - xM^*w)/(V_x - yM^*w)
  $$

- Then the angle $b_m$ is corrected with coefficient of kinematic interaction of screw with the hull $c$:

  $$b_m^* = c*b_m
  $$

- Afterwards angle $Y$ is defined $Y = d - b_m^*$ for entering the function $qR_{from\_St\_Psi}$ and $Teta_{from\_St\_Psi}$. 
Now we are able to calculate the value of resultant force $R$ of the propeller

$$R = qR*T0,$$

and angle of deviation of that force from diametral plane of the ship:

$$g = d + q.$$

This allows to define longitudinal and transversal forces, produced by rotated azipod:

$$FrX = qR*T0*\cos(d + q) \quad FrY = qR*T0*\sin(d + q)$$

and take them into consideration in two first differential equations.
Integration of equation system

- Let us add the last step of the algorithm – calculation of ship’s torque moment for the third equation from group of equations:

\[ Mr = Fr_X \cdot y_M + Fr_Y \cdot x_M \]

- All these steps of the algorithm are implemented for every azipod separately and during every cycle of integrating of the differential equations.
The main geometric parameters of the design scheme by Hoffmann A.D.

\[ \theta \] – angle of rotation of azipod,

\[ Y \] - angle of accumulation of current,

\[ q \] - angle of deviation of force R from azipod axis,

\[ g \] - angle of deviation of force R from diametral plane,

\[ j \] – angle of deviation of force R from direction of the current,

\[ \beta_M \] – local drift angle,

\[ R \] – resultant force on azipod,

\[ X, Y \] – projections of force R on diametral plane and perpendicularly to it,

\[ VA \] – vector of accumulated current.
Integration of equation system

- After having completed these steps, we are able to use software package for modelling any type of manoeuvring.

- All the parameters that were changed during the process are subjected to analysis.

- For that goal we must run a subprogram.
Subprogram

- Works for one azipod as well as for two, and in that case it records the following parameters of manoeuvring:
  - for the first azipod – forces X, Y; moment M; angles d and g, percentage of power, velocity Vx and Vy, angular velocity of rotating w, thrust screw stress, angle q, relative advance of propeller J, coefficient qR, angle Y, screw revolution Ns
  - the same parameters for the second azipod, but coordinates X, Y and course of the ship K are recorded instead of Vx, Vy, w
Software package demonstration

- A screenshot of interface form with hidden azipod control unit

- Composite trajectory of manoeuvring is generated by constant rotating of the second azipod and arbitrary rotating of the first azipod

- The aim of the trial is a demonstration of features of software package for obtaining parameters of manoeuvring with their further analysis. Particularly, to estimate influence of rotating the first azipod on the work of the second azipod.
Results of modelling

- There is no considerable relation between coefficient of the second azipod Qr2 and the angle of rotating of first azipod.
- This relation is very weak and indirect and appears due to change of conditions of flow along second azipod during the turn of the vessel.
- Torque moments of azipods change almost coherently when only the angle of rotating of first azipod is changed.
- Moments are considerably more sensible and alter unevenly almost simultaneously when only one azipod is being rotated.
The change of the rotating of azipods during the trial (top, °); change of coefficient $Q_{r1}$ of the resultant force of the first azipod depending on the angle of rotating of the first azipod (bottom)
Change of the coefficient $Q_{r2}$ of the resultant force of the second azipod depending on the angle of rotation of first azipod
Conclusion

- Mathematical model implemented in software is capable of working. It possesses convenient graphic interface for controlling the azipods of the vessel and allows to obtain the change of all the parameters of the vessel’s model during the process of manoeuvring.

- Interface of the program allows to fulfil adjustment of the model due to implementation of special operating modes, when two azipods are operated independently, synchronously and anisochronously. This feature gives the opportunity to control the calculations of functioning every azipod separately as well as their collateral work.
Conclusion

- It is shown that the work of one azipod influences the work of another through change in parameters of accumulating current. Every parameter does not change too dramatically when one azipod is rotated, but their simultaneous change considerably affects force characteristics of another azipod.

- Resolution IMO №137 of 05.12.2002 defines standard types of manoeuvres (acceleration, circulation, zigzag) for ordinary trial of mathematical model of the vessel, but for the case of the vessel with two azipods there are no such standards. The main objective is to create a set of base trials.