USE OF FUZZY CONTROL ELEMENTS IN ROBOT SYSTEM SYNTHESIS

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Abstract. At the Riga Technical University, in the Institute of Mechanics fuzzy control elements are investigated for applications to underwater robot movement by tail vibration and joint robot navigation by using slow motion synthesis. Basically the idea is realized in such a way that the interference in the management control system occurs only when the movement phase coordinates deviate in a given range. That makes it possible to adjust adaptive actuators to the proposed fuzzy control.

Keywords: underwater robot, control synthesis, fuzzy control, adaptive actuators.

Introduction

The first model investigated in this report is a fin type propulsive device of robotic fish moving inside water (Fig. 1.). The authors' reports before were aimed to find out the optimal control law of robot control when constraints of motion exist [1]. By variation of additional area of a vibrating tail (like horizontal pendulum, which ensures maximal positive impulse of motion forces components acting on a tail parallel to x axis) optimal motion control was found out (Fig. 1). To continue these investigations in this report the main aim for robot fish stable motion is to synthesise only one control action by fuzzy logic elements. In the second model synthesis of ship motion control by three independent control actions is investigated.

Synthesis of robot fish control

The robot fish model by fixing axe is shown in Fig. 1., 2.

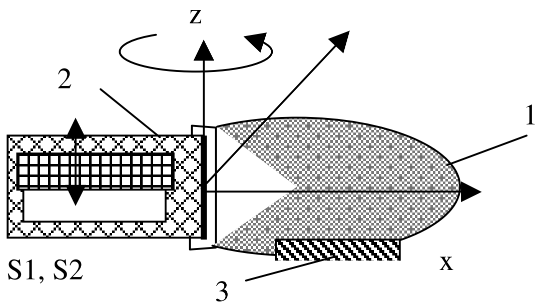

Fig. 1. **Side-view of a robot fish tail like horizontal pendulum:** 1 – body of robot; 2 – tail; 3 – fixed fundament

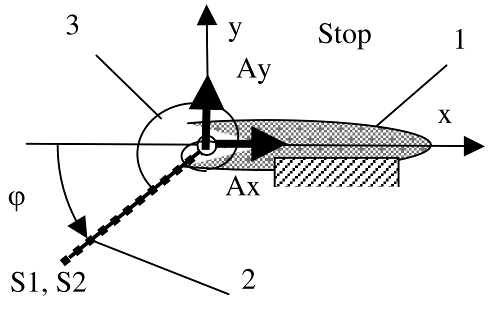

Fig. 2. **Top-view of a robot fish tail like horizontal pendulum:** 1 – body of robot; 2 – tail; 3 – spring of pendulum

Differential equation of the tail motion is:

$$J_A\ddot{\varphi} = M(t,\varphi,\dot{\varphi}) - c\cdot\varphi - k_t\cdot B\cdot sign(\dot{\varphi}\cdot\varphi)\cdot\int_0^L(\dot{\varphi}\cdot\xi)^2\cdot\xi\cdot d\xi\,, \tag{1}$$

where J_A – moment of inertia of the tail around the pivot point;
$\ddot{\varphi}$ – angular acceleration of a rigid straight tail;
$M(t,\varphi,\dot{\varphi})$ – excitation moment of the drive, for example, fuzzy control moment;
c – angular stiffness;
k_t – constant coefficient;
B – area;
$(\int_0^L(\dot{\varphi}\cdot\xi)^2\cdot\xi\cdot d\xi)$ – component of the moment of the resistance force expressed as an integral along the tail direction;
$\dot{\varphi}$ – angular velocity;
L – length of the tail.

From the principle of the motion of the mass centre C it follows (2):

$$m\cdot\left(\dot{\varphi}^2\cdot\frac{L}{2}\cdot\cos\varphi + \ddot{\varphi}\cdot\frac{L}{2}\cdot\sin\varphi\right) = Ax - k_t\cdot B\cdot\sin(\varphi)\cdot sign(\varphi\cdot\dot{\varphi})\cdot\left(\int_0^L(\dot{\varphi}\cdot\xi)^2\cdot d\xi\right) \tag{2}$$

After integration from equations (1) and (2) we have (3, 4):

$$\ddot{\varphi} = \frac{1}{J_A}\cdot\left[M(t,\varphi,\dot{\varphi}) - c\cdot\varphi - k_t\cdot B\cdot sign(\dot{\varphi})\cdot\dot{\varphi}^2\cdot\frac{L^4}{4}\right] \tag{3}$$

$$\begin{aligned}Ax = m\cdot\{\dot{\varphi}^2\cdot\frac{L}{2}\cdot\cos(\varphi) + \frac{1}{J_A}\cdot\left[M(t,\varphi,\dot{\varphi}) - c\cdot\varphi - k_t\cdot B\cdot sign(\dot{\varphi})\cdot\dot{\varphi}^2\cdot\frac{L^4}{4}\right]\cdot\frac{L}{2}\cdot\sin(\varphi)\} +\\ + k_t\cdot B\cdot\sin(\varphi)\cdot sign(\varphi\cdot\dot{\varphi})\cdot\dot{\varphi}^2\cdot\frac{L^3}{3}.\end{aligned} \tag{4}$$

The fuzzy control refers to functions $M(t,\varphi,\dot{\varphi})$ and B, given acceptable reaction Ax (4). Here infinitive solutions of synthesis of real motion of the robot exist. For example, functions $M(t,\varphi,\dot{\varphi})$ and B have separate control like harmonica time function and area borders B1, B2 exchange as next functions:

$$\begin{aligned}&Ax = m\cdot\{\dot{\varphi}^2\cdot\frac{L}{2}\cdot\cos(\varphi) +\\ &\frac{1}{J_A}\cdot\left[M0\cdot\sin(k\cdot t) - c\cdot\varphi - k_t\cdot\begin{bmatrix}B2\cdot(0{,}5 - 0{,}5\cdot sign(\varphi\cdot\dot{\varphi})) +\\ B1\cdot(0{,}5 + 0{,}5\cdot sig(\varphi\cdot\dot{\varphi}))\end{bmatrix}\cdot sign(\dot{\varphi})\cdot\dot{\varphi}^2\cdot\frac{L^4}{4}\right]\cdot\frac{L}{2}\cdot\sin(\varphi)\} +\\ &+ k_t\cdot\sin(\varphi)\cdot sign(\varphi\cdot\dot{\varphi})\cdot\dot{\varphi}^2\cdot\frac{L^3}{3}\cdot(B2\cdot(0{,}5 - 0{,}5\cdot sign(\varphi\cdot\dot{\varphi}) + B1\cdot(0{,}5 + 0{,}5\cdot sig(\varphi\cdot\dot{\varphi})).\end{aligned} \tag{5}$$

In this case an example of modelling of reaction Ax is shown in Fig. 3.

The main idea of this report of fuzzy control is to separate fast and slow motions of the robot fish motion. Its means that in the first stage of the investigations the robot corps is fixed. The tail fast rotation motion is calculated. After that (in the second stage) it is approximately assumed that the robot moves by acting (fuzzy) forces given in the first stage. An example of motion is shown in Fig. 3.

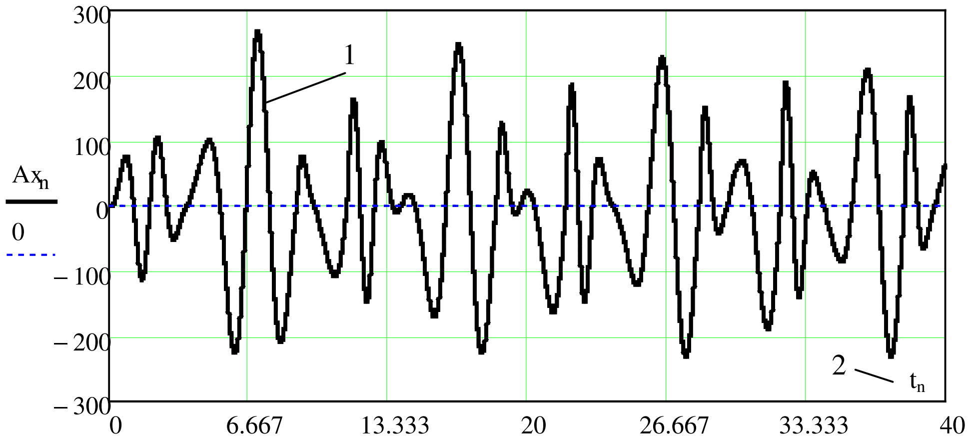

Fig. 3. **Axial reaction of tail:** 1 – reaction; 2 – time

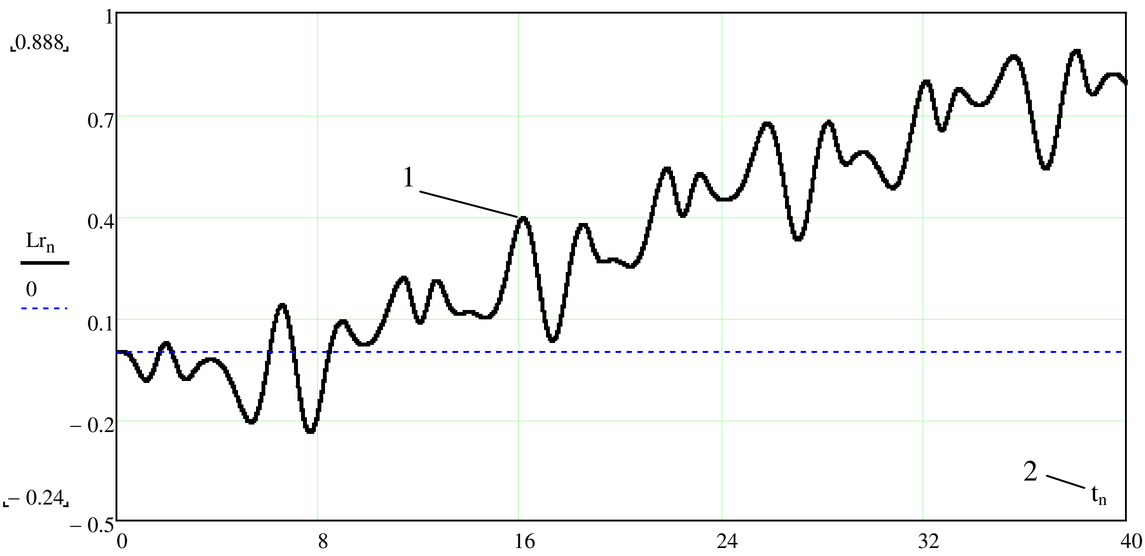

Fig. 4. **Fuzzy axial displacement of robot as time *t* function:** 1 – reaction; 2 – time

Ship motion control

The ship control model is shown in Fig. 5.

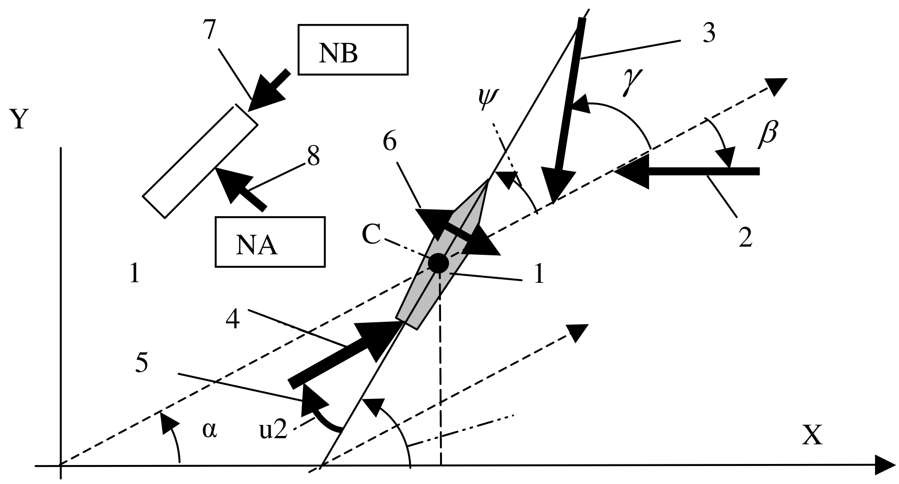

Fig. 5. **Ship control model:** 1 – body of ship; 2 – wind direction; 3 – flow direction; 4 – main control action force; 5 – angle of main control action force; 6 – additional front control; 7 – front resistance; 8 – side resistance

The ship has three control actions: main control action 4, angle of main control action 5 and front control action 6. In the common model like rigid body motion approximately the ship has six degrees of freedom. For visualisations and understanding of the control problem six differential equations of motion are shown from MathCad program by Eilers simple step calculation in Fig. 6 – 7.

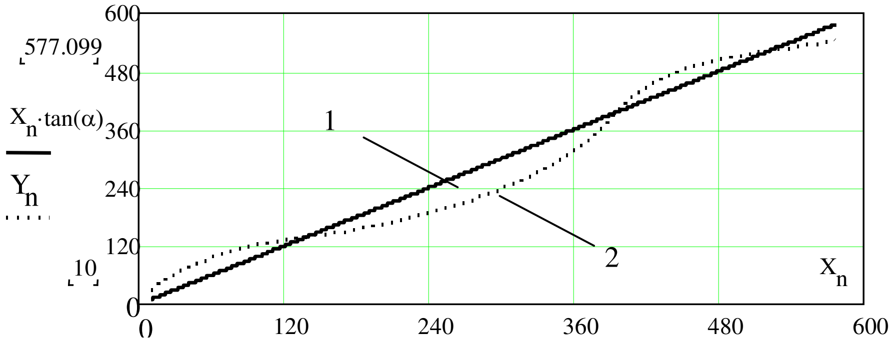

Fig. 6. **Ship control:** 1 – trace; 2 – ship motion takes into account all resistance and control forces

$$
\begin{pmatrix} X_{n+1} \\ vX_{n+1} \\ Y_{n+1} \\ vY_{n+1} \\ Z_{n+1} \\ vZ_{n+1} \\ \varphi_{n+1} \\ \omega x_{n+1} \\ \theta_{n+1} \\ \omega y_{n+1} \\ \psi_{n+1} \\ \omega z_{n+1} \end{pmatrix} :=
\begin{bmatrix}
X_n + s \cdot vX_n \\
vX_n + \frac{s}{m} \cdot \left[\begin{array}{l} \left[U1 \cdot \cos\left[\alpha + \psi_n - U2 \cdot \left[(1) \cdot \left(\text{sign}\left(X_n \cdot \tan(\alpha) - Y_n\right)\right) - K \cdot \text{sign}\left(\psi_n\right)\right]\right] - U3 \cdot \left(\text{sign}\left(X_n \cdot \tan(\alpha) - Y_n\right)\right) \cdot \sin\left(\alpha + \psi_n\right)\right] \ldots \\
+ \left[-k00 \cdot \frac{a}{L0} \cdot m \cdot g \cdot \left[\left[1 - \cos\left[2 \cdot \pi \cdot \frac{t_n \cdot \left[vX_n \cdot \left(\cos\left(\alpha - \beta + \psi_n\right) + vY_n \cdot \sin\left(\alpha - \beta + \psi_n\right)\right) + V0\right]}{L0}\right]\right] \cdot \cos(\alpha - \beta)\right]\right] \ldots \\
+ k0 \cdot (-1) \cdot (A2 \cdot B2 + 2 \cdot A2 \cdot C2) \cdot \left[\cos\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \cos\left(\alpha + \psi_n\right) + vY_n \cdot \sin\left(\alpha + \psi_n\right) + Vs \cdot \cos\left(\psi_n - \gamma\right)\right)\right] \ldots \\
+ \left[-k1 \cdot A1 \cdot C1 \cdot \sin\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vv \cdot \sin\left(\psi_n + \beta\right)\right)^2\right] \ldots \\
+ \left[-k2 \cdot B1 \cdot C1 \cdot \cos\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \cos\left(\alpha + \psi_n\right) + vY_n \cdot \sin\left(\alpha + \psi_n\right) + Vv \cdot \cos\left(\psi_n + \beta\right)\right)^2\right] \ldots \\
+ \left[\begin{array}{l} -k3 \cdot A2 \cdot C2 \cdot \sin\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vs \cdot \sin\left(\psi_n - \gamma\right)\right)^2 \ldots \\ + \left[-k4 \cdot B2 \cdot C2 \cdot \cos\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \cos\left(\alpha + \psi_n\right) + vY_n \cdot \sin\left(\alpha + \psi_n\right) + Vs \cdot \cos\left(\psi_n - \gamma\right)\right)^2\right] \end{array}\right] \end{array} \right] \\
Y_n + s \cdot vY_n \\
vY_n + \frac{s}{m} \cdot \left[\begin{array}{l} \left[U1 \cdot \sin\left[\alpha + \psi_n - U2 \cdot \left[(1) \cdot \left(\text{sign}\left(X_n \cdot \tan(\alpha) - Y_n\right)\right) - K \cdot \text{sign}\left(\psi_n\right)\right]\right] + U3 \cdot \left(\text{sign}\left(X_n \cdot \tan(\alpha) - Y_n\right)\right) \cdot \cos\left(\alpha + \psi_n\right)\right] \ldots \\
+ \left[-k00 \cdot \frac{a}{L0} \cdot m \cdot g \cdot \left[\left[1 - \cos\left[2 \cdot \pi \cdot \frac{t_n \cdot \left[vX_n \cdot \left(\cos\left(\alpha - \beta + \psi_n\right) + vY_n \cdot \sin\left(\alpha - \beta + \psi_n\right)\right) + V0\right]}{L0}\right]\right] \cdot \sin(\alpha - \beta)\right]\right] \ldots \\
+ \left[-k0 \cdot (A2 \cdot B2 + 2 \cdot A2 \cdot C2) \cdot \left[\sin\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \cos\left(\alpha + \psi_n\right) + vY_n \cdot \sin\left(\alpha + \psi_n\right) + Vs \cdot \cos\left(\psi_n - \gamma\right)\right)\right]\right] \ldots \\
+ \left[k1 \cdot A1 \cdot C1 \cdot \cos\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vv \cdot \sin\left(\psi_n + \beta\right)\right)^2\right] \ldots \\
+ \left[-k2 \cdot B1 \cdot C1 \cdot \sin\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) + vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vv \cdot \cos\left(\psi_n + \beta\right)\right)^2\right] \ldots \\
+ \left[\begin{array}{l} k3 \cdot A2 \cdot C2 \cdot \cos\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vs \cdot \sin\left(\psi_n - \gamma\right)\right)^2 \ldots \\ + \left[-k4 \cdot B2 \cdot C2 \cdot \sin\left(\alpha + \psi_n\right) \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) + vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vs \cdot \cos\left(\psi_n - \gamma\right)\right)^2\right] \end{array}\right] \end{array} \right] \\
Z_n + s \cdot vZ_n \\
vZ_n + \frac{s}{m} \left[-m \cdot g - cz \cdot Z_n - k01^2 \cdot vZ_n + k00 \cdot (-a \cdot cz) \cdot \cos\left[2 \cdot \pi \cdot \frac{t_n \cdot \left[vX_n \cdot \left(\cos\left(\alpha - \beta + \psi_n\right) + vY_n \cdot \sin\left(\alpha - \beta + \psi_n\right)\right) + V0\right]}{L0}\right]\right] \\
\varphi_n + s \cdot \omega x_n \\
\omega x_n + \frac{s}{Jx} \cdot \left[\begin{array}{l} k1 \cdot A1 \cdot C1 \cdot 1 \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vv \cdot \sin\left(\psi_n + \beta\right)\right)^2 \cdot e1 \cdot 1 \ldots \\
+ k3 \cdot A2 \cdot C2 \cdot 1 \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vs \cdot \sin\left(\psi_n - \gamma\right)\right)^2 \cdot e2 \cdot 1 \ldots \\
+ k00 \cdot \frac{a}{L0} \cdot m \cdot g \cdot \left[\left[1 - \cos\left[2 \cdot \pi \cdot \frac{t_n \cdot \left[vX_n \cdot \left(\cos\left(\alpha - \beta + \psi_n\right) + vY_n \cdot \sin\left(\alpha - \beta + \psi_n\right)\right) + V0\right]}{L0}\right]\right] \cdot \sin\left(\psi_n + \beta\right) \cdot e3\right] \ldots \\
+ \omega y_n \cdot \omega z_n \cdot (Jy - Jz) - cT1 \cdot \varphi_n - bT1 \cdot \omega x_n \end{array} \right] \\
\theta_n + s \cdot \omega y_n \\
\omega y_n + \frac{s}{Jy} \cdot \left[\begin{array}{l} k1 \cdot A1 \cdot C1 \cdot 1 \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vv \cdot \sin\left(\psi_n + \beta\right)\right)^2 \cdot e1 \cdot 1 \ldots \\
+ k3 \cdot A2 \cdot C2 \cdot 1 \cdot \left(vX_n \cdot \sin\left(\alpha + \psi_n\right) - vY_n \cdot \cos\left(\alpha + \psi_n\right) + Vs \cdot \sin\left(\psi_n - \gamma\right)\right)^2 \cdot e2 \cdot 1 \ldots \\
+ k00 \cdot \frac{a}{L0} \cdot m \cdot g \cdot \left[\left[1 - \cos\left[2 \cdot \pi \cdot \frac{t_n \cdot \left[vX_n \cdot \left(\cos\left(\alpha - \beta + \psi_n\right) + vY_n \cdot \sin\left(\alpha - \beta + \psi_n\right)\right) + V0\right]}{L0}\right]\right] \cdot \cos\left(\psi_n + \beta\right) \cdot e4\right] \ldots \\
+ \omega x_n \cdot \omega z_n \cdot (Jz - Jx) - cT2 \cdot \theta_n - bT2 \cdot \omega y_n \end{array} \right] \\
\psi_n + s \cdot \omega z_n \\
\omega z_n + \frac{s}{Jz} \cdot \left[U3 \cdot \left(\text{sign}\left(X_n \cdot \tan(\alpha) - Y_n\right)\right) \cdot e4 + U1 \cdot \sin\left[U2 \cdot \left[\left(X_n \cdot \tan(\alpha) - Y_n\right) \cdot \left(\text{sign}\left(X_n \cdot \tan(\alpha) - Y_n\right)\right) - K \cdot \text{sign}\left(\psi_n\right)\right]\right] \cdot e3 - \left(bT3 \cdot \omega z_n\right) + \omega x_n \cdot \omega y_n \cdot (Jx - Jy)\right]
\end{bmatrix}
$$

Fig. 7. **Motion modeling equations**

To understand the idea of the fuzzy control action in this case the region of not to interaction is shown in Fig, 8. When motion is inside the region of the track the control action is switched out. When the objet crosses the bounds of the track the control action starts remove the object back to the desired neutral region.

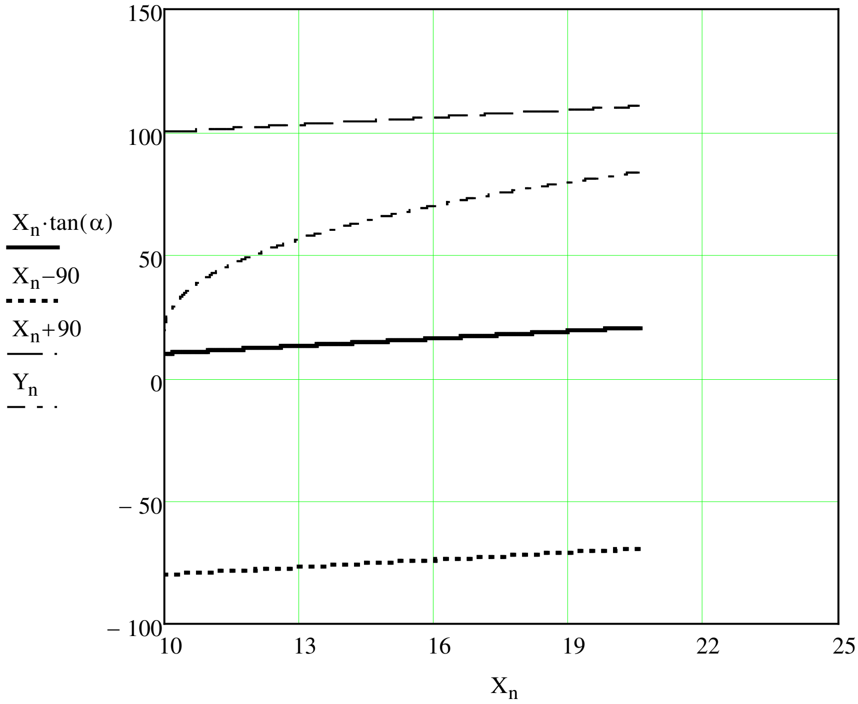

Fig. 8. **Region of not to interaction**

Results and discussion

Motion of robotic systems vibration by simplified interaction with the water flow can be described by rather simple equations for motion analysis. That allows to solve the mathematical problem of area control optimization and to give information for new systems synthesis. Control (or change) of the object area under water allows to create very efficient mechatronic systems. For realization of such systems adapters and controllers must be used. For this reason very simple control actions have solutions with use of sign functions. Examples of synthesis of real mechatronic systems are given. One example of synthesis is a system with time-harmonic moment excitation of the tail in the pivot. The second example of synthesis is ship motion control by tree interactions.

Conclusions

Fuzzy control elements do not need to follow precision objects motion equations and interaction parameters. It is enough to control some parameters of motion (like phase coordinates - displacement, velocity) by sensors and add additional control actions to the system by actuators. Basically the idea is realized in such a way that the interference in the management control system occurs only when the movement phase coordinates deviate in a given range. That makes it possible to adjust adaptive actuators to the proposed fuzzy control.

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