Simulation of Non-Linear Robot Position-Controller for Improvement of Adaptivity

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Abstract -**In general, control methods are based on the laws of linear controls. However, the operation of realized controllers can also go over into non-linear domain, mainly because of the motor-voltage-limit.**

This paper investigates the features of non-linearity using a model-driven process improve the adaptive properties of non-linear control. This process based on the analysis of parametric relationships in the functions through the use of model simulations.

I. INTRODUCTION

Position control of robots is desirable in the aperiodic approach of target, without overshooting.
It is known that many robot controllers are non-linear. The gain of control loop for a critical damped case is calculable with classic methods for linear control loops, however we can only give an approach for non-linear control loops. Using advanced simulation methods and tools (e.g. Matlab Simulink) we can model the real system nearly in the desired level of the operation, consequently we can derive such results from the simulation which are used in the design.
The aim of this thesis to create and investigate a model for adaptive non-linear position-control, in which an experimental function takes the influences of the changing inertia into consideration for the gain, which is desirable while the robot is moving.
This functions are based on running many simulations. The Fig. 1 shows the model. There is no current limitation in this model. The calculated heat-loss I^2Rt is low.
The gain is P-type, the loop is 1-type because of the integration [3]. Θ_r is a rotation reference signal .
If we take an axis 1st of an R6-type robot into consideration when the 2nd and 3rd axis are moving, the value of inertia can be changed by the variation of configuration maybe in the 1:100 ratio.

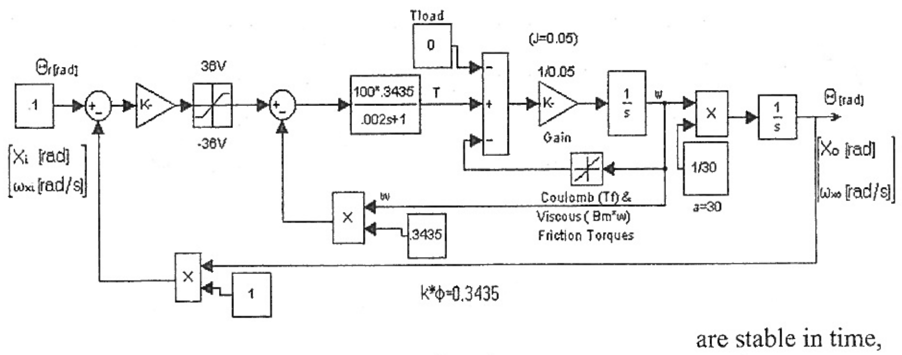

Figure 1. Model of position controlled robot link driven by permanent magnet DC motor.

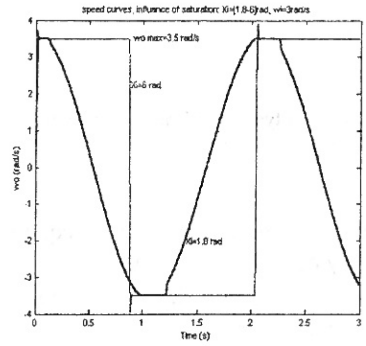

Figure 2: Speed curves in case of saturation: ω_{in}=const, *Xi*=1.8 and 6 rad

We can preset the value of Coulomb and Viscous friction in the model. With regard to the effect of friction-reduction of PWM controlled motor, we set the value of Coulomb friction low. Practically there is no backlash in modern robot-constructions.
The value of the load torque is zero in steady-state, there is not contact force during the movement of the robot TCP, since the movement of the robot is unrestricted. The gear-ratio is 1:30.

II. THE FEATURES OF NON-LINEARITY

In this case the non-linearity of the control-loop derives from the voltage-limit (36V in our case).
This value 36V value permits a speed of 3.5 rad/s the 1. link. This speed is sufficient to follow a relatively low frequency or amplitude input signals (Fig. 2 and 3)
The well-known features are as follows:
- the value of the output signal depends on also the magnitude of the input signal,
- the method of the describing-function is based on the following conditions :
  - the parameter values of the of non-linear elements are stable in time,
  - there are no constant or subharmonic components

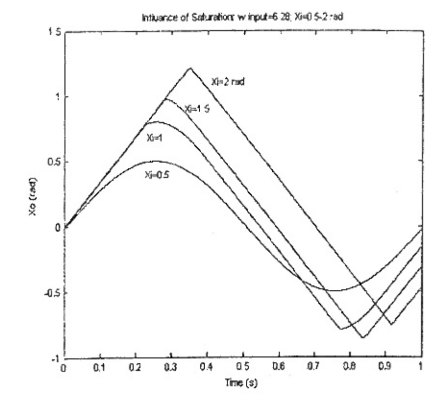

Figure 3: Influence of saturation-type non-linearity in case of sinusoidal input, ω_{in} =const

in the output signal,

- the output signal is periodic and its frequency is equal to the frequency of the input signal,
- there is only one non-linearity in the loop.

The disadvantages are as follows:

- verifying accuracy is difficult in this way;
- the process can be used for only quantitative estimation;
- the time-domain behavior is cannot be estimated.

The features of the non-linearity, applied in our model is shown in Fig . 4.

In the describing-function we take only the 1[st] harmonic into account [4]:

$X_{o1}(t)=B_1 sin\omega t+A_1 cos\omega t$. Be it:

$C_1=(B_1^2+A_1^2)^{1/2}$, $sin\varphi_1=A_1/C_1$, $cos\varphi_1=B_1/C_1$. With this we describe: $X_i(j\omega)=B$, $X_{o1}(j\omega)=C_1 e^{j\varphi 1}$.

According to the describing-function, the quotient of the signal amplitudes of output X_o and input X_i can be given by the following expression :

$N(B,j\omega)=C_1(B,j\omega)e^{j\varphi 1(Bj\omega)}/B$, where

$X_i(j\omega)=B$, $X_{o1}(j\omega)= C_1 e^{j\varphi 1}$. The figure shows that in linear section the transfer constant is A_n. If the amplitude of input is sinusoidal, if $X_i=B>b$ then output X_o is shaped cut away.

$X_o(t)=A_n X_i(t)= A_n B sin\omega t$, $\quad 0 \leq \omega t \leq \alpha$,

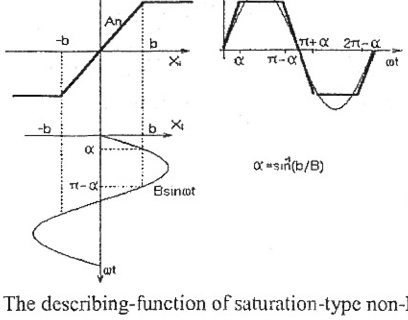

Figure 4: The describing-function of saturation-type non-linearity

$X_o(t)= A_n b$, $\quad \alpha \leq \omega t \leq \pi-\alpha$,

$X_o(t)= A_n X_i(t)= A_n B sin\omega t$, $\quad \pi-\alpha \leq \omega t = \pi$,

where b is an input-value that produces the saturation,

and $\alpha=sin^{-1}(b/B)$. $A_1=0$,

$$B_1=(2/\pi)\int_0^{\alpha} A_n B sin^2\omega t d\omega t+2/\pi\int_{\alpha}^{\pi-\alpha} A_n b\, sin\omega\, d\omega t+$$

$$+2/\pi\int_{\pi-\alpha}^{\pi} A_n B\, sin^2\omega t d\omega t.$$ After integration

$B_1=(2/\pi) A_n B[\alpha+ sin2\alpha/2]$.

Here $C_1=B_1$ and $\varphi_1=0$,

$N(B,j\omega)=(2/\pi)A_n[\alpha+sin2\alpha/2]=N(B)$, $B\geq b$.

If $B>b$, the value of the function is less then A_n, but if $B\leq b$, the behavior of the function is the same as the behavior of the linear element with value A_n.

The above-mentioned features are shown in Fig 5.

Here the maximum speed of the angle is ω=3.5 rad/s, and is unable to follow a bigger speed input signal. The maximum gradient of output X_o means the limit of speed, derived from the voltage limit of the motor.

Another important feature of control is the effect of saturation-type non-linearity on accuracy.

If the input of the control demands a greater-then - possible speed at the output due to the saturation, then the control output can cause very significant distortion (see Fig.6). Parameters of employed sinusoid signals for investigation and the computed maximum values of speeds from this are shown in title of figures.

The features of following are of minor importance in usual tasks of robotics when the robot approaches their target. However in case of following of the trajectory it's very important to follow punctually the input of the control, mostly in the movement rectilinear or circular, otherwise this link of the robot will no in the position required in

time prescribed.

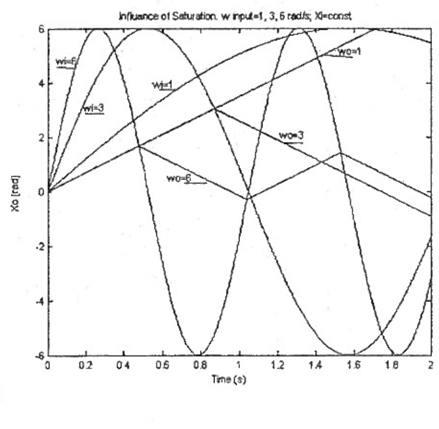

Figure 5: Influence of saturation ω_{in}=1,3,6 rad/s, X_i=const

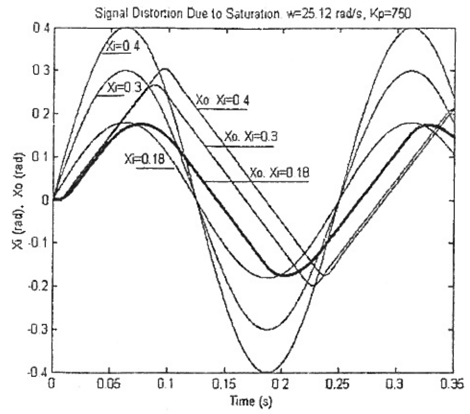

Figure 6. Distortion of output signal due to the saturation. ω=25.12 rad/s, ***Xi*** variable

Hence maybe no realized the coordinated movement among in axis of robot, consequently the movement will no the shape prescribed.
Because of the saturation the possible value of speed is ω=3.5 rad/s (on 1st axis) as mentioned in introduction. The Fig. 7 shows the curves of speed on peaks which of looks the distortion if the speed is in the domain of non-linearity.

The visible alterations are derived from the changing the values of the gain, the inertia and the friction. The Fig. 8 shows the output signal of the position control regarding to changing the gain ***Kp*** (here the inertia and friction are constant).
The Fig. 9 shows the influence of vary of Viscous-friction, at values 0.09 and 0.0009. Here are the gain ***Kp***=1200, ω=25.12 rad/s, ***J***=0.05 kgm^2.
The alterations timely or in shape indicate the features of followings. The influence of Viscous –friction is of no significance, the delay is 5-15 millisecond, is can be shown only by magnifying.
The influence of changing of values of the inertia and

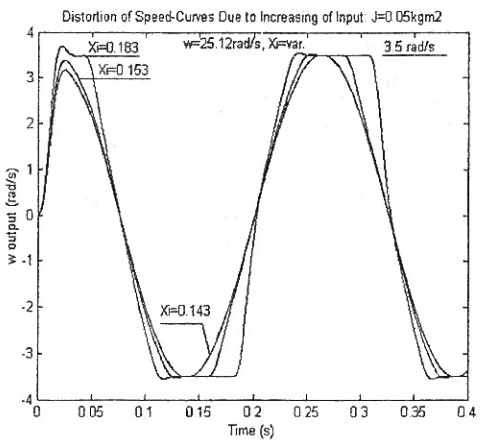

Figure 7: Distortion of speed-curves due to non-linearity

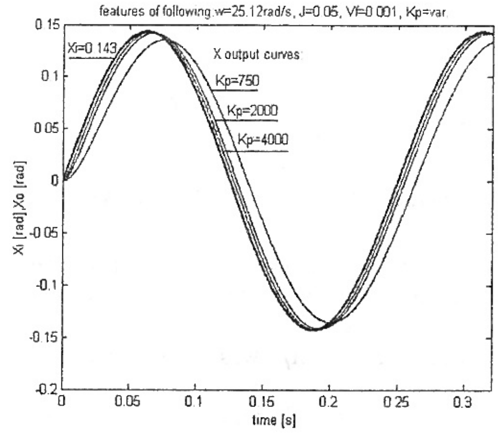

Figure 8. Features of following at changing gain, ***Kp***

the gain are more important in the delay, however this cause no distortion.
It's known that delay decreases with application the higher value of gain and this is noticeable in that cases too. Considering that the setting time of position control is also decreasing at higher value of gain, it is expedient to set the gain to a highest value as possible.

III. IMPROVING THE ADAPTIVITY OF CONTROL

Control can shift from overdamped to underdamped mode while following a single trajectory. Underdamped control is undesirable in an industrial robot, as overshot can cause damage to the objects the robot is manipulating, hence, controllers are tuned to give near critically damped response at normal operating speed. At high speed the inertial loads change rapidly, and at low speed some robots move with noticeable vibration [1].
All these dynamic effects generate disturbances which cause errors in following of trajectory, hence robot designers try to keep the loop-gains as high as possible.

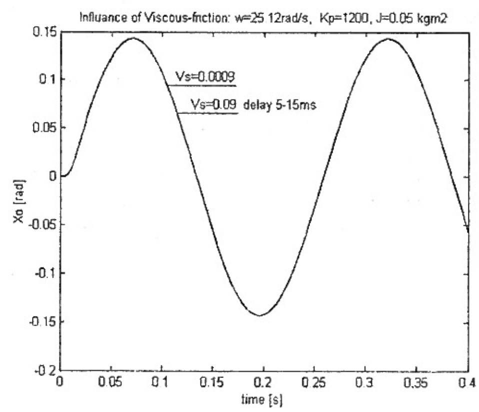

Figure 9: Influence of change of Viscous-friction

Adaptive control systems adjust the gain of the control loops in order to maintain critical damping over a range of manipulator configuration.

A. Finding the values of function $Kp(\Theta_r)$ and $Kp(J)$

For improve the adaptivity of non-linear control we need to know the relationship between the suitable gain and the actual values of inertia.
Running the model, the gain (***Kp***) was variable, while

the reference signal of angle of rotation (Θ_r) and inertia (***J***) were constant. Here ***J*** means $J_{reduced}$.

We have done numerous model-runs to find the value of gain which produces a minimal time aperiodic course. In these investigations Θ_r was changed between 0.0001 and 6 radian, and ***J*** was changed between 0.0005 and 0.05 kgm^2. The resulted curves ***Kp(J)*** at Θ_r=const are shown in Fig. 10.
Note that the influence of change of inertia decreases at values higher Θ_r.
We can draw a conclusion that in strongly saturated non-linear position control the function between the critical gain-values and inertia is approximately hyperbolic.

B. Approximations with 2nd, 3rd, 4th, 5th order polynomials.

The polynomials calculated by Matlab. The ones of curves are shown in Fig. 11.

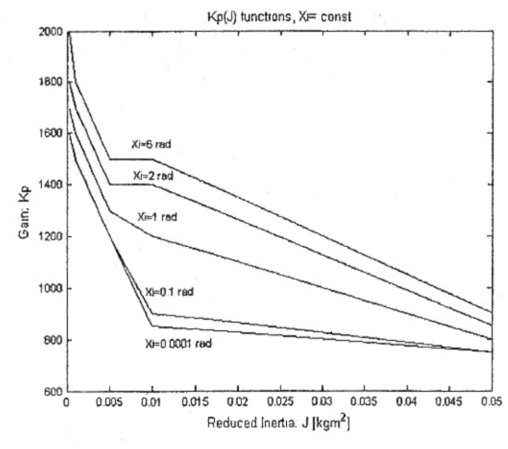

Figure 10: ***Kp(J)*** functions of control loop (see fig.1), resulted minimal time aperiodic approaches.

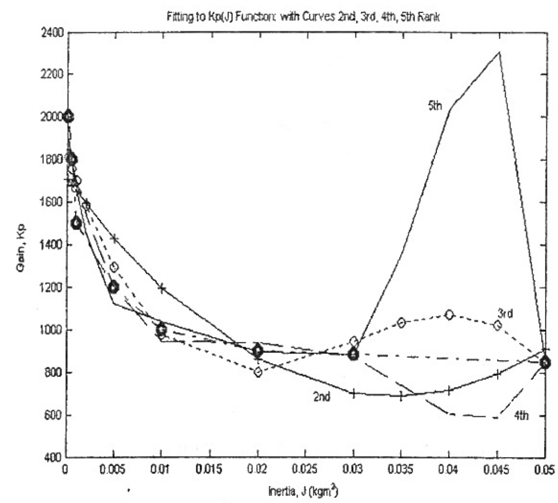

Figure 11: 2nd, 3rd, 4th and 5th order approximations of ***Kp(J)*** function.

The curve 5th order are can not be used, because their inaccuracy is unacceptable at values of ***J*** between 0.03-0.05 . The application of the curve 2nd and 4th order is possible with compromise, because the values of ***Kp*** at values ***J***=0.025-0.045 is too less.
The approximations with polynomials result lower inaccuracy in those cases when the reference signal is higher.

C. Approximations with a hyperbolic function

In the case Θ_r=const we can fit a hyperbolic function on the ***Kp(J)*** curve. It can be fitted a function given by expression $Kp=[350/J^{0.21}+130]$ on Θ_r. This function was derived from this investigations. (See Fig 12.) The shape of ***Kp*** reflects the monoton nature of the function ***Kp(J)***.

The adaptive position control model used a hyperbolic approximation function can be shown in Fig. 13.
The control loop given by an actual value of inertia calculates the actual value of gain ***Kp***. Deficiency of that model it does not take into consideration the function $Kp(\Theta_r)$, so it is necessary to reduce ***Kp*** to its critical value.

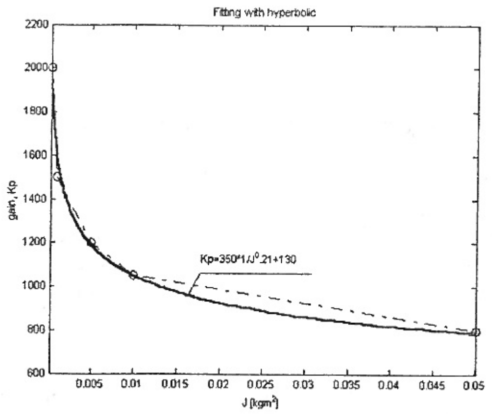

Figure 12: Approximation of the ***Kp(J)*** function with hyperbolic

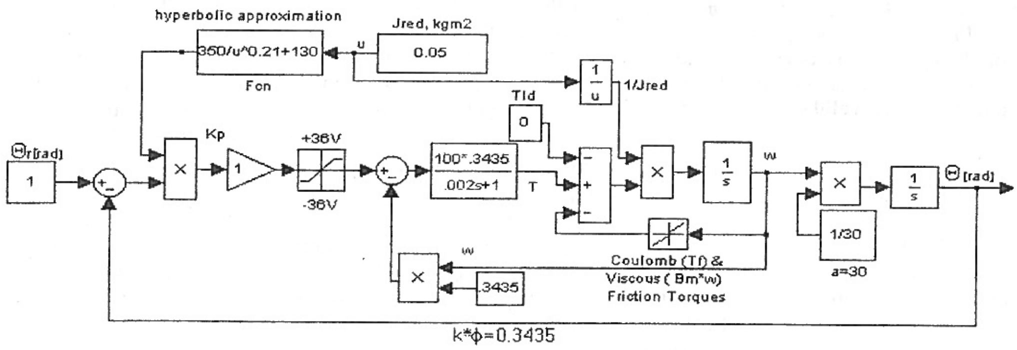

Figure 13: Inertia-adaptiv control model operating with a ***Kp(J)*** hyperbolic function

D. Application of a linearly interpolated 2-variable function

In the model Matlab generates continuous function from values ***Kp(J)*** and ***Kp***(Θ_r) which are given in vector- format, with a linear interpolation, on Fig. 14.

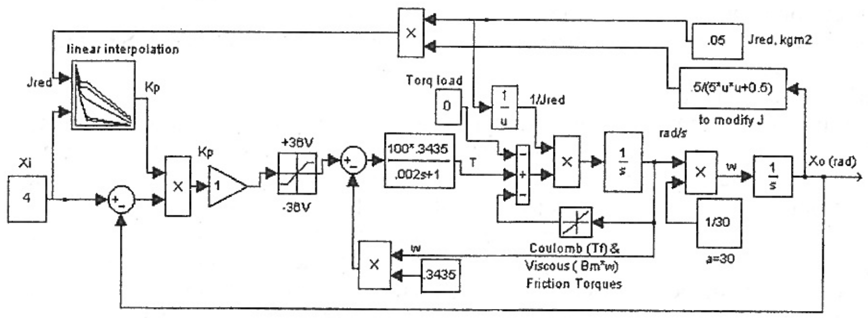

Figure 14. : Control model with linear interpolation of ***Kp(J,*** X_i) and a modification of inertia under robot going a given trajectory from outside to inside. X_i is a step-form reference signal.

Here the model does not take into calculation the changing of inertia derived by concrete alterations of configuration in robot moving, by the lack of a concrete robot-model. Instead of this as a specific example we introduced an assumption:
the trajectory of robot is going from outside to inside on a special trajectory of length 4 radian and the value of ***J'*** decreases from 0.05 to 0.0005 kgm^2. The model calculate the gain ***Kp(J)*** with this function : ***J(length of trajectory).***

IV. CONCLUSIONS

The operation of saturation type non-linear position control can properly be modeled and investigated with simulation methods. It was found that the minimum time aperiodic approach of the target can be solved even with highly change parameters. These functions can be determined, and their applications realize a better behavior in the operation of the control.

V. REFERENCES

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