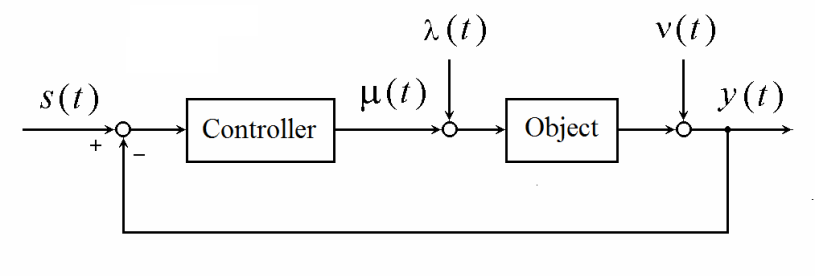
The Predictive Control Principle and Perspectives of it Application in Automatic Control Systems

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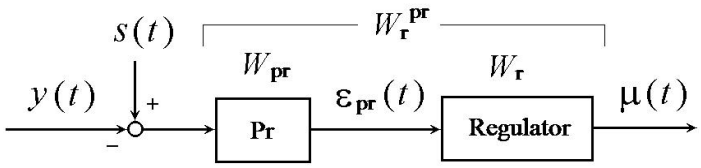
Linear automatic control systems
with standard algorithms (P, PI, PID) and inertial object

The **standard control principle** on current state of control output



$$\mu(t) = A\{y(t)\}$$

It is offered to pass to
the **predictive control principle** on future output $y(t+\tau_{pr})$



$$\mu(t) = A\{y(t+\tau_{pr})\}$$

$$\varepsilon_{pr}(t) = \varepsilon(t+\tau_{pr}) = s(t) - y(t+\tau_{pr})$$

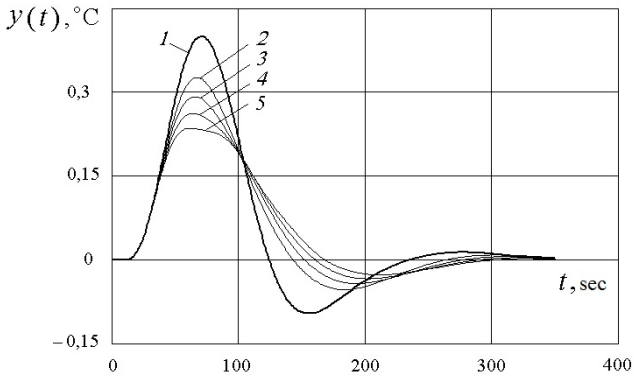
Realization of this principle allows to increase significantly quality of regulation

One-loop system

Example: steam temperature of a boiler with PID regulator and object

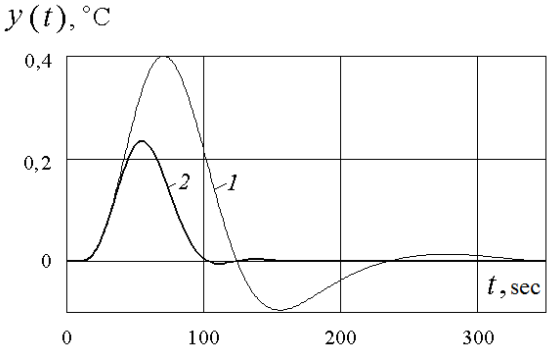
$$W_{\mu}(p) = \frac{k_{\mu}}{(T_1 p + 1)(T_2 p + 1)(T_3 p + 1)} e^{-\tau_{\mu} p},$$

$k_{\mu} = -1{,}75$ ºC/(kg/sec); $\tau_{\mu} = 8$ sec; $T_1 = 40$ sec; $T_2 = 44$ sec; $T_3 = 10$ sec



1 — with ordinary PID-controller; *2*, *3*, *4*, *5* — with predictive PID-controller τ_{pr} = 8 sec (*2*); 12 sec (*3*); 16 sec (*4*); 20 sec (*5*)

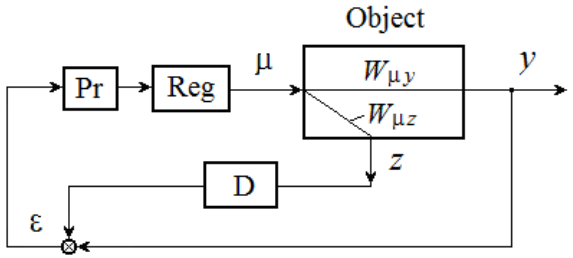
Retuning



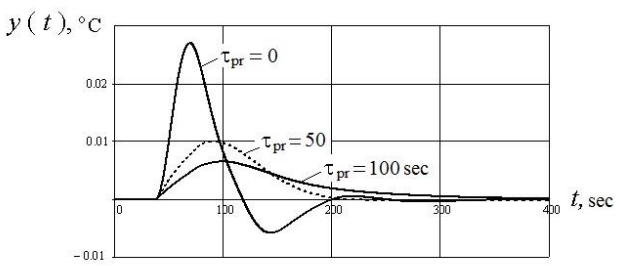
The integrated square criterion I_2 is reduced by **4.4** times, the dynamic error y_{din} by **1.8** times, and regulation time by **3** times less than in system with usual PID regulator

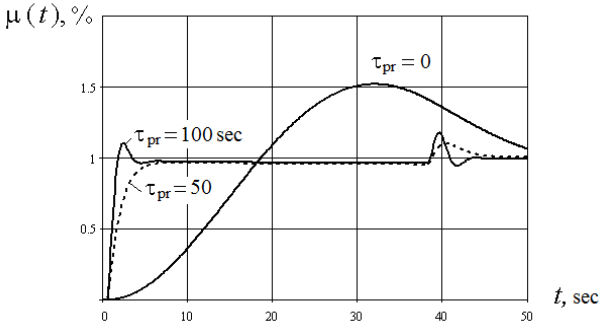
Two-loops ACS

Double-circuit schemes with an additional signal from quick-response intermediate value z. As an example: boiler secondary steam overheat with differentiator and PI regulator.



$$W_{\mu y}(p)=\frac{0.421}{(49p+1)^2}e^{-38p}\ \frac{^\circ C}{\%\mu};\quad W_{\mu z}(p)=\frac{0.62(298p+1)}{(136p+1)(41p+1)(12p+1)}\ \frac{^\circ C}{\%\mu}.$$

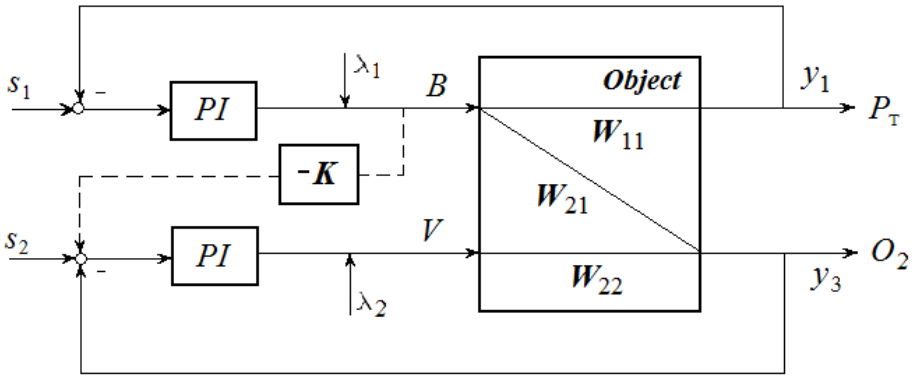




In comparison with usual system (a curve $\tau = 0$) value of a dynamic mistake y_{din} decreases by **4** times at increasing the prediction time to 100 sec, and integrated square criterion I_2 — almost by **10** times. At the same time at predictive control the range of movement of regulation devise $\mu(t)$ considerably decreases and the stability reserve in an external contour increases. **Result**: reducing twice the range of a output deviation in one-loop and by 3 times **—** in double-circuit systems.

Two-connected system

Example: the boiler system “fuel — air”



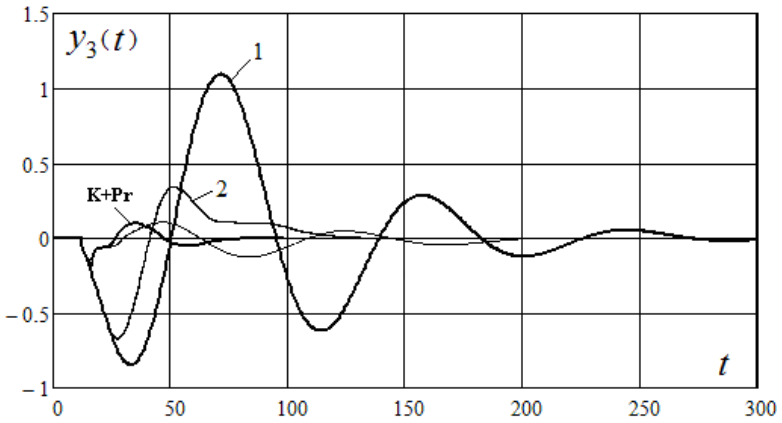
$$W_{11}(p)=\frac{7.6}{290\,p+1}e^{-10\,p}\ \frac{kg/sm^2}{10^3\ m^3/h}$$

$$W_{22}(p)=\frac{0.075}{30\,p+1}e^{-13\,p}\ \frac{\%O_2}{10^3\ m^3/h}$$

$$W_{21}(p)=\frac{-0.69}{30\,p+1}e^{-10\,p}\ \frac{\%O_2}{10^3\ m^3/h}$$

Ideal compensator: $K_{id}(p)=\dfrac{W_{21}(p)}{W_{22}(p)W_{r2}(p)}=\dfrac{-9.2\,p}{19.90\,p+0.94}e^{+3\,p}$

Rational compensator: $K_{rat}(p)=\dfrac{-9.2\,p}{19.90\,p+0.94}$



1 — ordinary system without compensator;
2 — predictive system without compensator
***K*+*Pr* —** predictive system with predictive compensator;
***K*—** predictive system with rational compensator

If rational compensator in ordinary system permits to decrease the integral square criterion I_2 (or variance) by 8 times, the predictive compensator decreases I_2 by 25 times. The addition to predictive compensator the predictive control principal gives the decreasing square criterion by 60 times with 11 times less the dynamic mistake y_{din} and 3 times less time of regulation.

The tuning PID-controller by one parameter (the predictive time) with unknown object's dynamic characteristics

Idea: it is consider the PID-controller as a predictive PI-controller.
The equation of linear predictor is

$$y(t+\tau_{pr}) = y(t) + y'(t)\tau_{pr}.$$

Its transfer function will be

$$W_{pr}(p) = 1 + p\tau_{pr}.$$

So the transfer function of predictive PI-controller will has the form of PID-controller

$$W_{PI}^{pr}(p) = W_{PI}(p)W_{пр}(p) = \left(k_r + \frac{k_r}{T_i p}\right)(1 + p\tau_{pr}) =$$

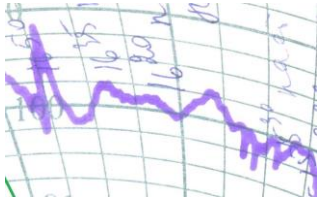
$$= k_r\left(1 + \frac{\tau_{pr}}{T_i}\right) + \frac{k_r}{T_i p} + k_r\tau_{pr}p = k_r\left(1 + \frac{T_d}{T_i}\right) + \frac{k_r}{T_i p} + k_r T_d p = W_{PID}(p),$$

with increasing gain $k_r^{pr} = k_r\left(1 + \frac{T_d}{T_i}\right)$ and differential time $T_d = \tau_{pr}$.

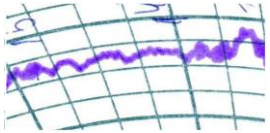
Tuning procedure:

1) Set any parameters of PI-controller (prefer with small safe stability).
2) Change the time of prediction until to receive the good result.

Example: The pasteurizing temperature control system of milk plant.



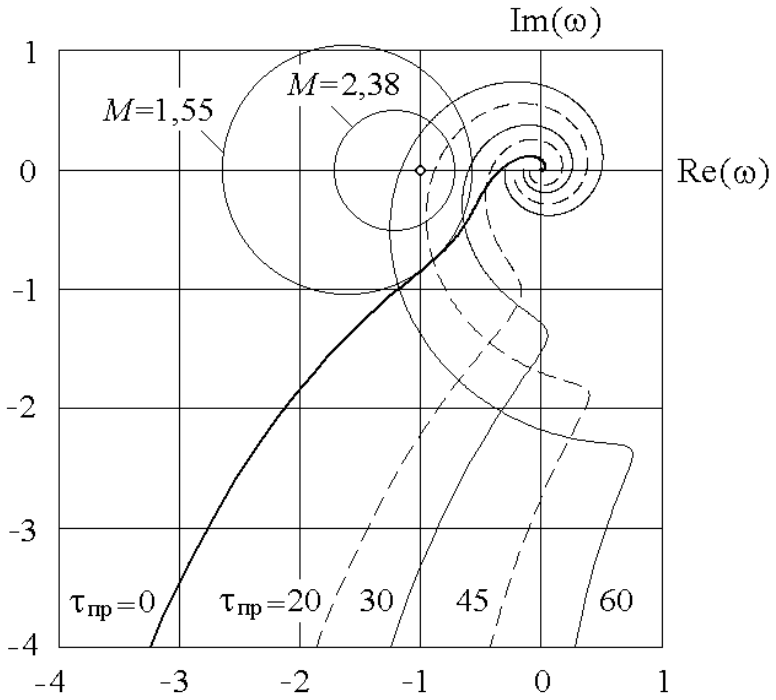
а)



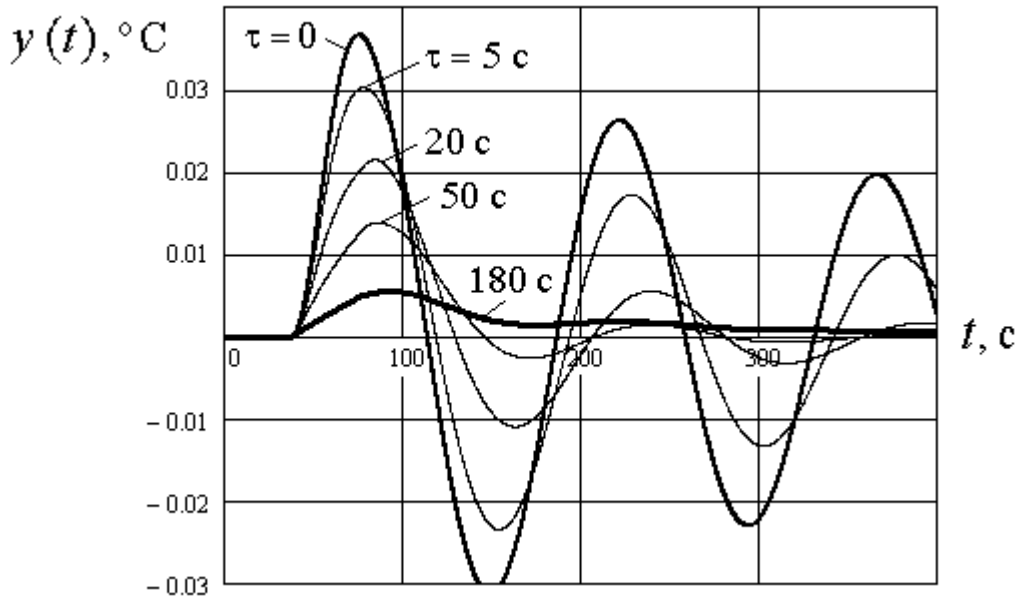
б)

а) $k_r = 0.68$, $T_i = 42$ s, $T_d = 5$ s; *б*) $k_r = 0.76$, $T_i = 47$ s, $T_d = 10$ s

The best tuning: $k_r = 0.8$; $T_i = 50$ s; $T_d = 12$ s.
Despite on approximate tuning we had got 6 times less the range of temperature variation.



Complex frequency characteristics unclosed system


y (t), °C
τ = 0
τ = 5 c
20 c
50 c
180 c
0.03
0.02
0.01
– 0.01
– 0.02
– 0.03
0
100
200
300
t, c