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FUZZY CONTROL OF THE ANTILOCK BRAKING SYSTEM OF THE PLANE'S LANDING GEAR

The present ABS controller of the braking system of the MiG21 aircraft induces high stresses of its components due to the bang-bang type controller. Thus, a smoother controller should be used to protect both the mechanical components and the braking system itself. A suitable controller was considered to be the Fuzzy Controller, based on the Mamdani approach.

BRAKING PHENOMENON BASICS

Fig. 1 depicts a wheel during the braking process The notations used in the picture have the following assignments:

T_{br} – applied braking torque;
L_w – wheel load;
Z_w – ground's vertical reaction;
X_w – ground's horizontal reaction (due to the applied braking torque);
ω_w – wheel's angular speed;
v – vehicle's speed;
r_w – dynamic tire radius;
T_{rol} – viscous friction torque (insignificant);
$I_w \frac{d\omega_w}{dt}$ – wheel's inertia moment [1, 2].

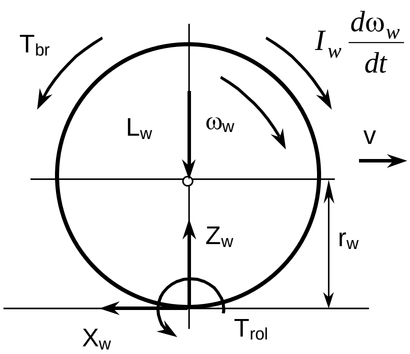

Fig. 1 Wheel during braking

According to this figure, the motion equation can be written after dividing it with $L_w r_w$, like:

$$\frac{I_w}{r_w Z_w}\frac{d\omega_w}{dt}-\frac{T_{br}}{r_w Z_w}+\mu_x \quad (1)$$

where, as above mentioned, the viscous friction torque was neglected.
As known, the braking process can't be approached without taking into consideration the grip (adherence) between the wheel and the road's surface. This is expressed by the dependence of the grip coefficient on the axial direction μ_x on the wheel relative slip on the road's surface given by:

$$s=\frac{v-\omega_w r_w}{v}\cdot 100\,[\%] \quad (2)$$

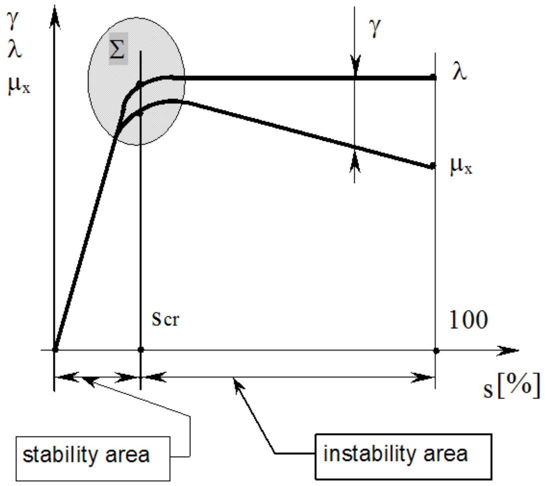

Fig. 2 Variation of the specific coefficients versus slip, during ABS assisted braking

The curve is plotted experimentally and has the shape given by fig. 2, different qualitative shapes needing experimental research.

If rewrite the equation (1) using the definitions: $\frac{I_w}{r_w Z_w}\frac{d\omega_w}{dt}=\gamma$ and $\frac{T_{br}}{r_w Z_w}=\lambda$, one could get [1]:

$$\gamma-\lambda+\mu_x=0 \quad (3)$$

The evolution of these three terms versus slip is depicted in fig. 3. As seen here, optimal brake appears if the applied braking torque keeps his value within the shadowed area.

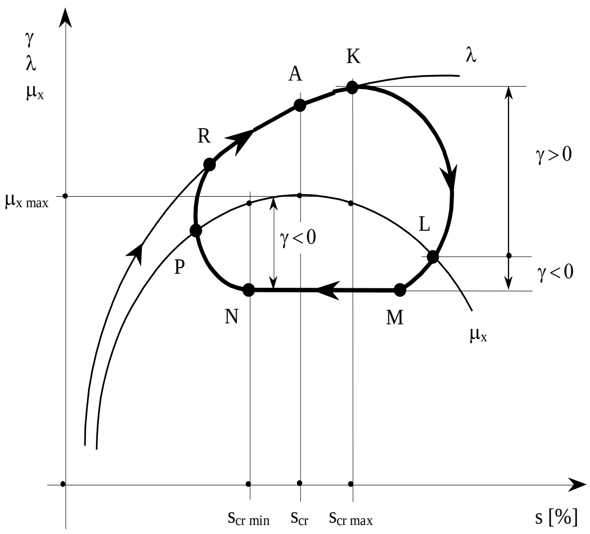

Fig. 3 The variation of γ, λ and μ_x versus slip during ABS assisted braking process

THE BEHAVIOR OF THE ABS BRAKED WHEEL

The ABS braking principle is easily understood concerning the Σ area depicted in fig. 2. In this area, the λ coefficient (braking moment dependant) leaves the common curve which it previously made with the road grip μ_x showing the fact that the applied braking torque is kept at his maximum value, or at a value which leads inevitable to the wheel's lock. Thus, fig. 3 that represents a magnified picture of the specified area, marks a critical slip s_{cr}, which is usually implemented into the ABS logic.

The tuning parameter of the braking process when ABS used is given by the wheel deceleration (particularly by the γ coefficient of the main equation), but taking into account the preset acceptable slip (usually about 20%).

Fig. 4 depicts the shapes of the time-dependant braking characteristic curves when braking with or without ABS. The higher the working frequency of the ABS, the smaller the steps of the "stair" and hence, the shorter the braking time and space, for a given road surface (grip).

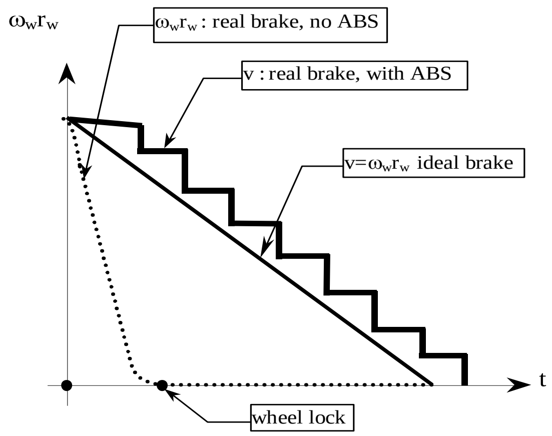

Fig. 4 The shapes of the characteristic curves during braking with and without ABS

SIMULATION RESULTS

In this chapter a comparison between the present and the proposed control systems will be taken into account. That will allow a better balance between the system's actual behavior and the expected fuzzy controlled one, underlining both the advantages and the disadvantages of these two different approaches [2, 4].

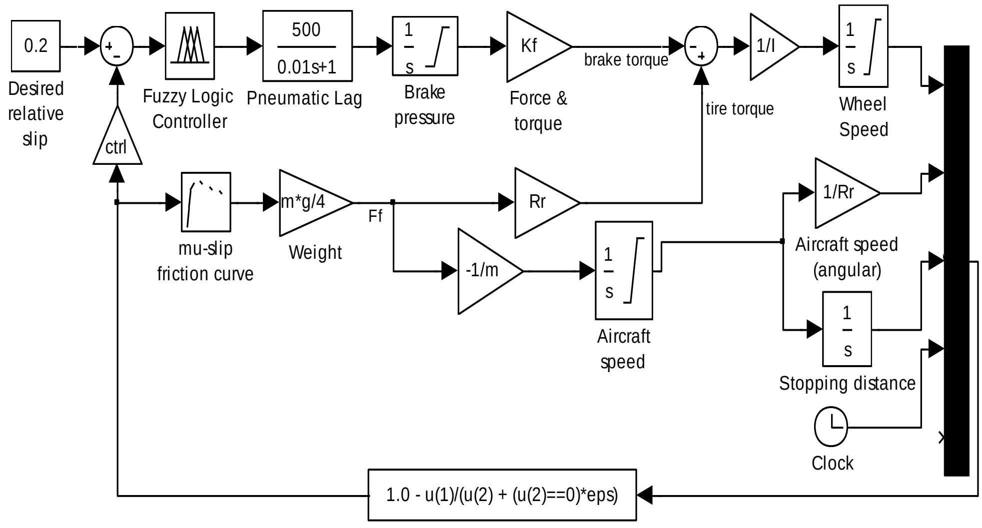

Fig. 5 The Simulink diagram, the ABS braking model

According to the present system's configuration, we considered that the proper model would be the one featured by a bang-bang relay, which was only supposed to replace the fuzzy controller pictured in fig. 5.

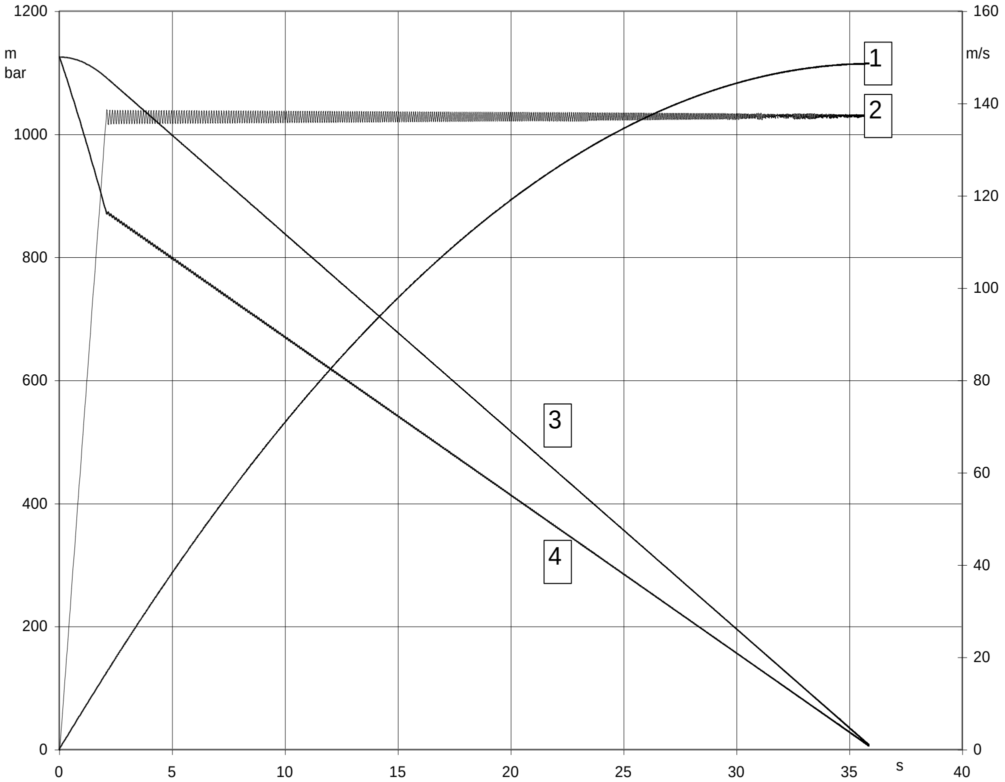

Fig. 6 The variation of the main braking parameters while using the present controller

The MiG 21 aircraft features were taken into account when simulating the braking process both with the bang-bang controller and the fuzzy logic controller. The landing mass was 6000 kg, the chosen landing speed was 200 km/h, the wheel radius was 0.4 m and the landing runway was chosen as dry asphalt, with a 0.7 maximum grip coefficient. All the data needed to feature the pneumatic and the mechanical components the system were achieved experimentally by the aircraft specialists.
Fig. 6 depicts the behavior of the main braking parameters when using the present controller working on the plane's landing gear [3].
If replacing the bang-bang controller with a Mamdani Fuzzy Logic controller [4] one gets the behavior depicted in fig. 7. As seen in this picture, the pressure

variation is fine smoothed, thus the mechanical and pneumatic stresses of the braking components are significantly decreased.
The applied rule base furnished the following input and output membership functions, given in the fig. 8 and 9.

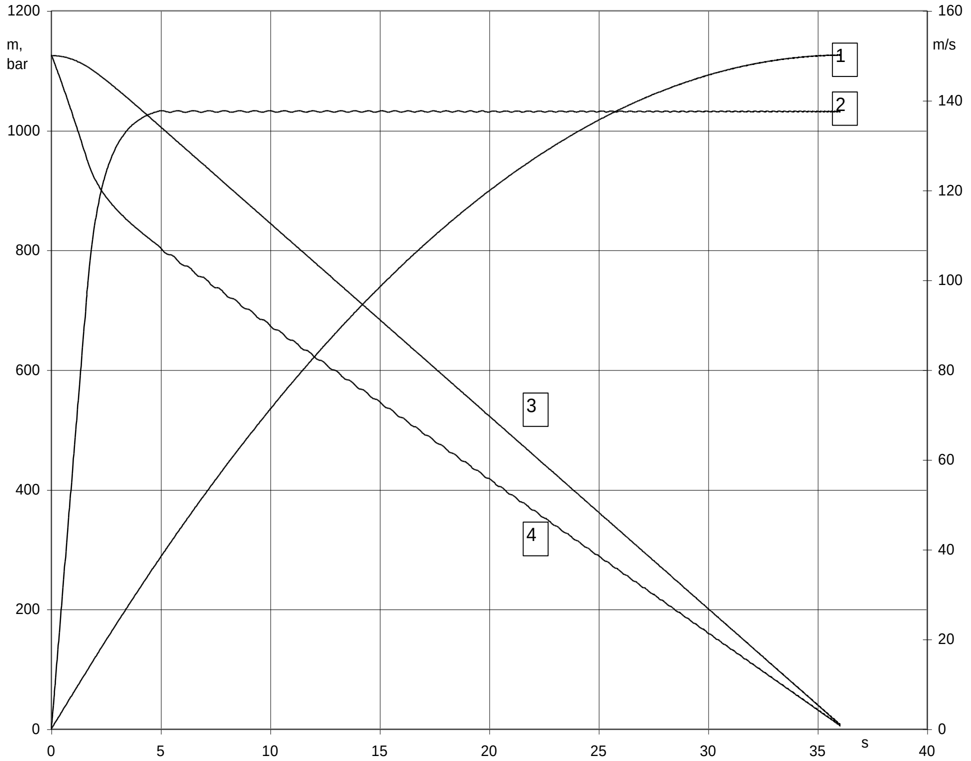

Fig. 7 The variation of the main braking parameters while using a Mamdani Fuzzy Logic controller

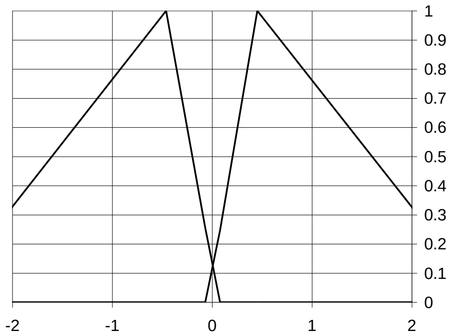

Fig.8 Input membership functions

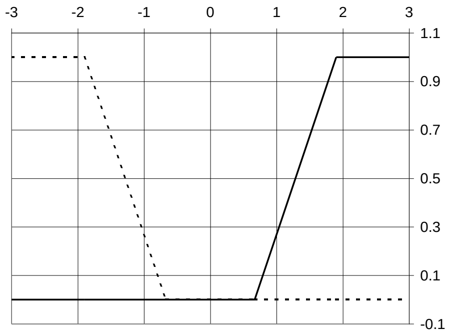

Fig. 9 Output membership functions

A very important feature that should be balanced was the space used by the aircraft until it's final stop. As a matter of fact, a smoother behavior of the applied pressure, hence, of the applied braking torque, will inevitable lead to an increased stopping distance. But as the simulation results revealed, the stopping distance isn't too much bigger when using the Fuzzy Logic controller instead of the bang/bang controller. Thus, the stopping distance according to the present system is of 1110 m, while the stopping distance when using the Fuzzy Logic controller is of 1130 m. The difference means about 2%, that assumes an affordable value.

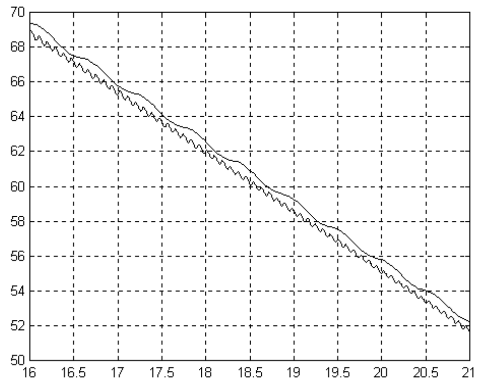

Fig. 10. Comparison between the wheel's angular speed fluctuation for the bang-bang controller (down) and the FL controller (up)

A better comparison between these two types of controllers can be seen in fig. 10, where the wheel's angular speed fluctuation versus time have been zoomed for a certain period of braking time, both for the actual bang-bang controller and the fuzzy logic controller. As noticed, the bang-bang controller' angular speed fluctuation is beneath the fuzzy logic one, so the actual controller is more effective than the proposed one, resulting in a shorter stopping distance, but on the other hand the actuating system is subjected to a much harder, periodical oscillation.

CONCLUSIONS

The fuzzy logic controller leads to a slight increase of the stopping distance, but the benefits brought to the mechanical and pneumatic equipment of the landing gear's braking system are significant. Further simulation using different fuzzy logic rule bases have been developed but no significant improvements have been achieved. Even the pressure curve kept on smoothening, the stopping distance increased significantly, so they have been aborted.

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