SILESIAN UNIVERSITY OF TECHNOLOGY

FACULTY OF AUTOMATIC CONTROL, ELECTRONICS
AND COMPUTER SCIENCE

FINAL PROJECT

MODELING AND SIMULATION OF CHOSEN PHYSIOLOGICAL PHENOMENA

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direction: Macrofaculty

specialization: Information Processing for Control

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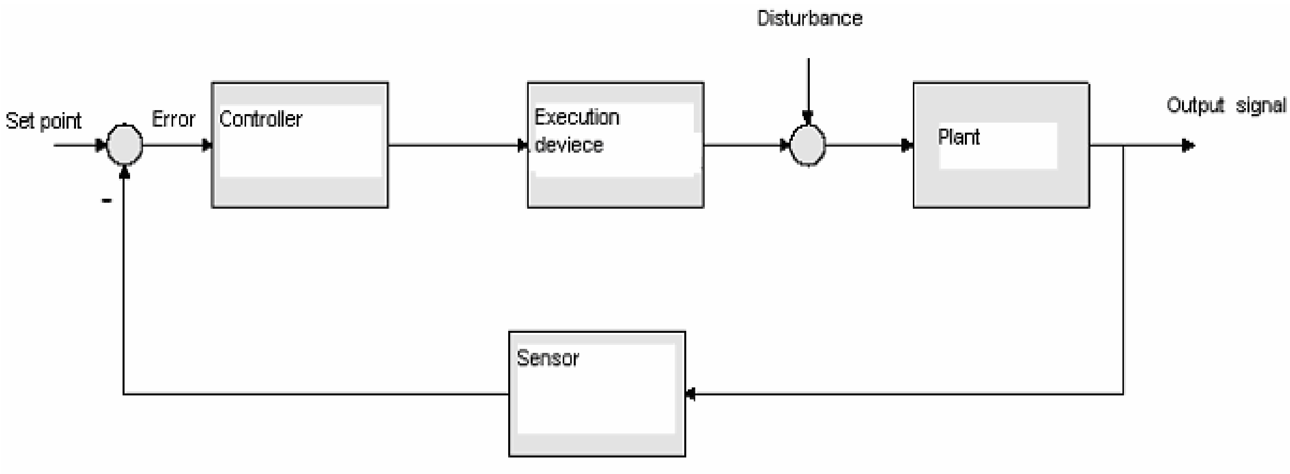
2. Comparison of basic control theoretic and physiological control concepts in human organism.

2.1 Point of view of control theory.

Negative feedback is one of the most important solutions that supports performance of automatic control systems. It is applied in great majority of automatic regulation circuits that are widely used not only in industry but also in other domains of life. System with negative feedback show small sensitivity on disturbance and variation of parameters, and its construction is possible even at in complete knowledge of dynamic objects property. Importance of negative feedback is tremendous and it is difficult to overestimate it [4].



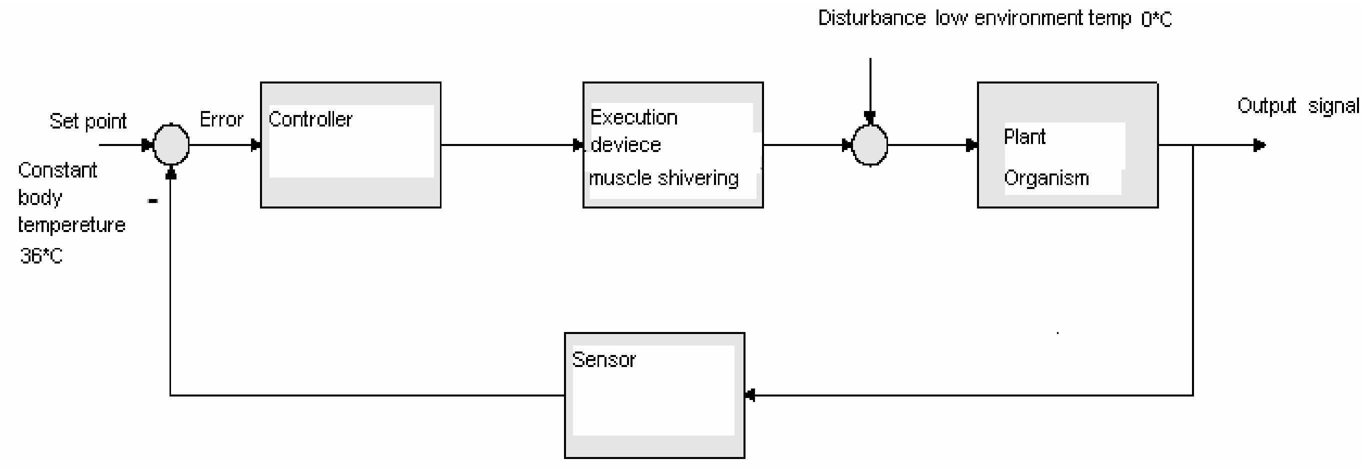
Scheme of close loop system.

We may consider above scheme as a heating system. Its aim is to provide a temperature in the room (plant) according to set point. Let us assume that temperature outside room decreases (disturbance). It results in change of temperature inside the room according to some function which results in the value of output signal. It is measured by temperature sensor and compared to set point (desired room temperature).A signal resulting from comparison is applied on input of the controller that adjust heater (execution device) to increase the temperature in the room.

2.3 Point of view of control theory in physiological control.

Definition of negative feedback from physiological control point of view may be stated in following way:

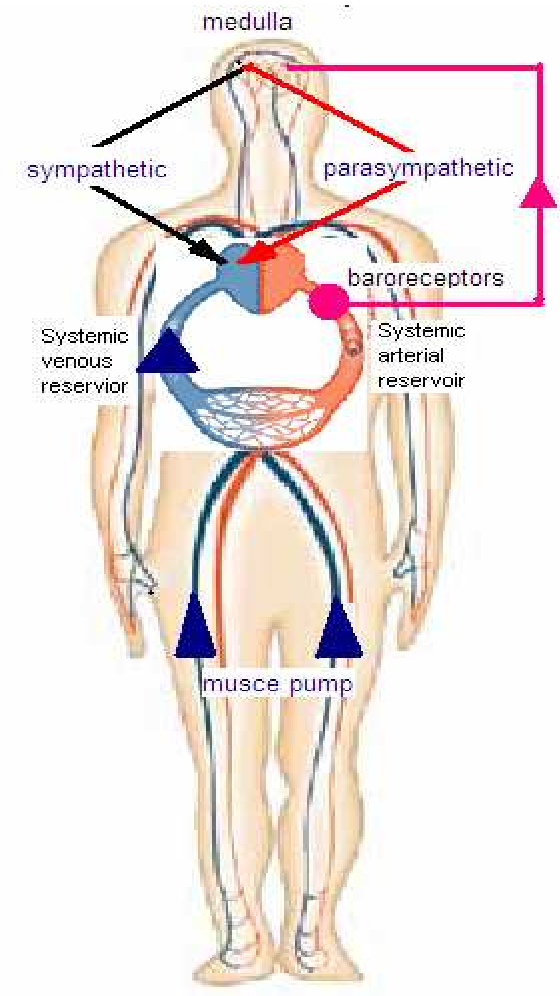
"Stimulus acting on organism initiates a series of inner organism changes that cause weakening or even eliminating influence of this stimulus".



Example of close loop in physiological system.

Applying analogy with control theoretic point of view presented previously, we may model one of feedback loops in human organism related to providing constant temperature in body. Stimulus (environment temp. 0ºC) is equivalent to disturbance, organism may be compared to plant, nervous system can be considered as sensor and controller, muscles (that produce heat during shivering) are execution devices [3].

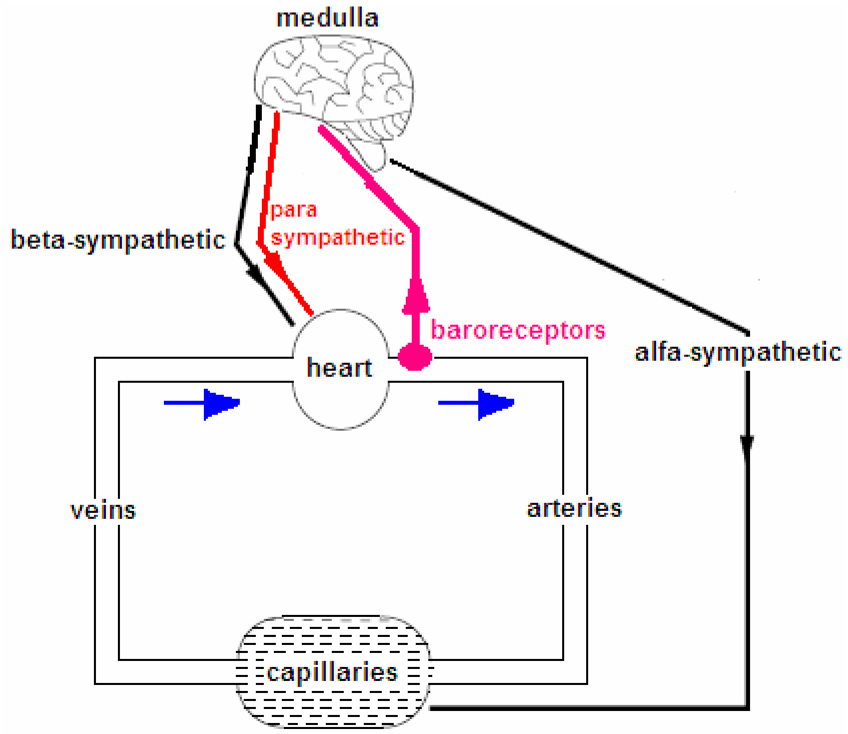
3.3 Basics of baroreflex control.



Short-term baroreflex cardiac control system.

During pedaling and overcoming applied load, muscle pump speeds up blood flow in the direction of heart. It is connected with increase of blood pressure in systemic venous reservoir. During intense effort the rise of pressure in veins can reach 10 – 15 mm Hg [4]. When pumped blood reaches heart, it forces increase of heart stroke volume (input of heart pump has to match raise of blood flow from output of muscle pump). Left heart chamber is responsible for providing blood across systemic arterial reservoir back to capillaries – increased blood amount (forced raise of stroke volume) is needed to be ejected at a relatively high pressure. The increase of pressure on output of left chamber is detected by baroreceptors that are nerve fiber endings in arterial walls. They are sensitive to the average arterial blood pressure and to the rate at which blood pressure increases. Rise of blood pressure results in firing more signals to the medulla

5.3 Mathematical description of the system.



Short – term baroreflex cardiac control system.

Equations for the conservation of average non-pulsatile blood volume look as follows:

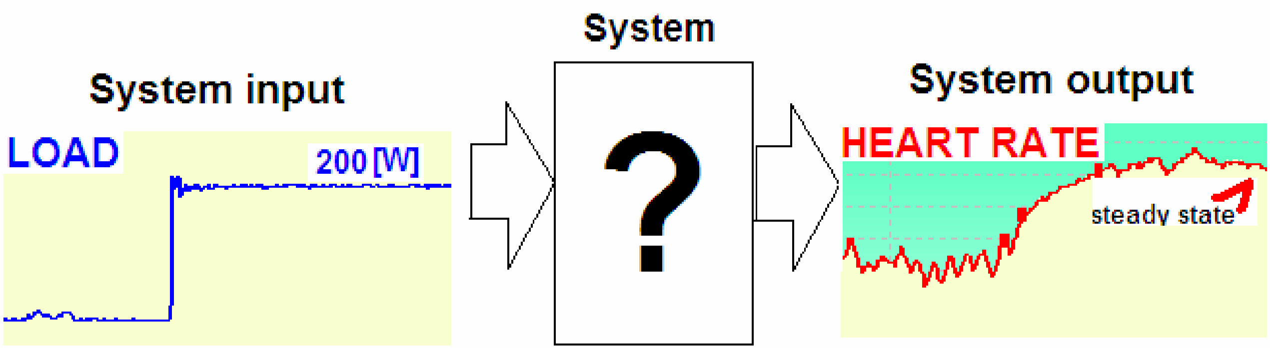
$$C_v \dot{p}_v = \frac{(p_a - p_v)}{R_c} - \frac{p_v}{R_v}$$

$$C_a \dot{p}_a = -\frac{(p_a - p_v)}{R_c} + H \Delta V$$

where : p_a - mean arterial pressure,
*p_a - time rate of change of arterial pressure,
p_v - mean venous pressure,
C_a - compliance of the arterial system,
C_v – compliance of venous system,
R_c – resistance to flow through the arterial system,
R_v - resistance to flow through the venous system,
H – heart rate,
ΔV – stroke volume (the volume pumped out in one heart beat).

6. Simple model describing competition between sympathetic and parasympathetic system from point of view of sport physiologist/cycling coach.

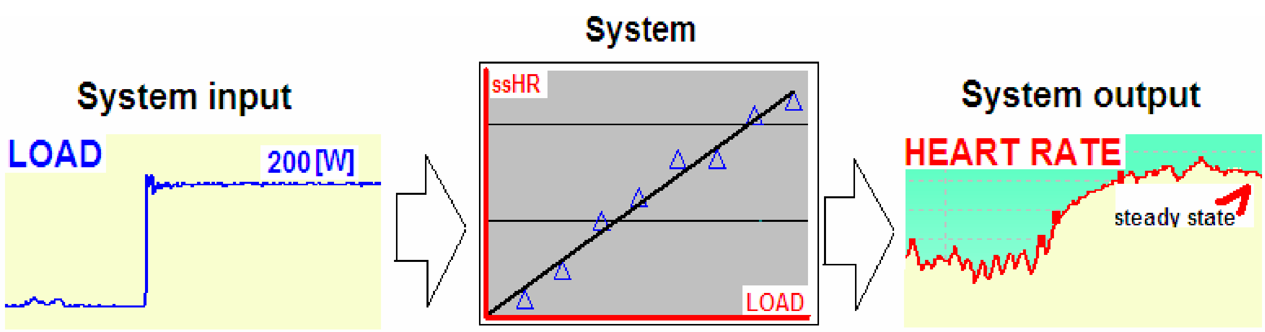
6.1 General assumptions of model.



General model idea.

The first question that I decided to ask was – what might be important to a coach/physiologist in a model that describes a cyclist organism when input load and heart rate are taken into consideration?

The most important would be that a model in a proper way describe value of heart rate in a steady state for every applied load. In order to obtain such a model it would be enough to take an advantage of proper data from performance test that describes relation between load and heart rate in steady state and fit proper curve to obtained results forming relation LOAD = f(ssHR) as it is presented below.



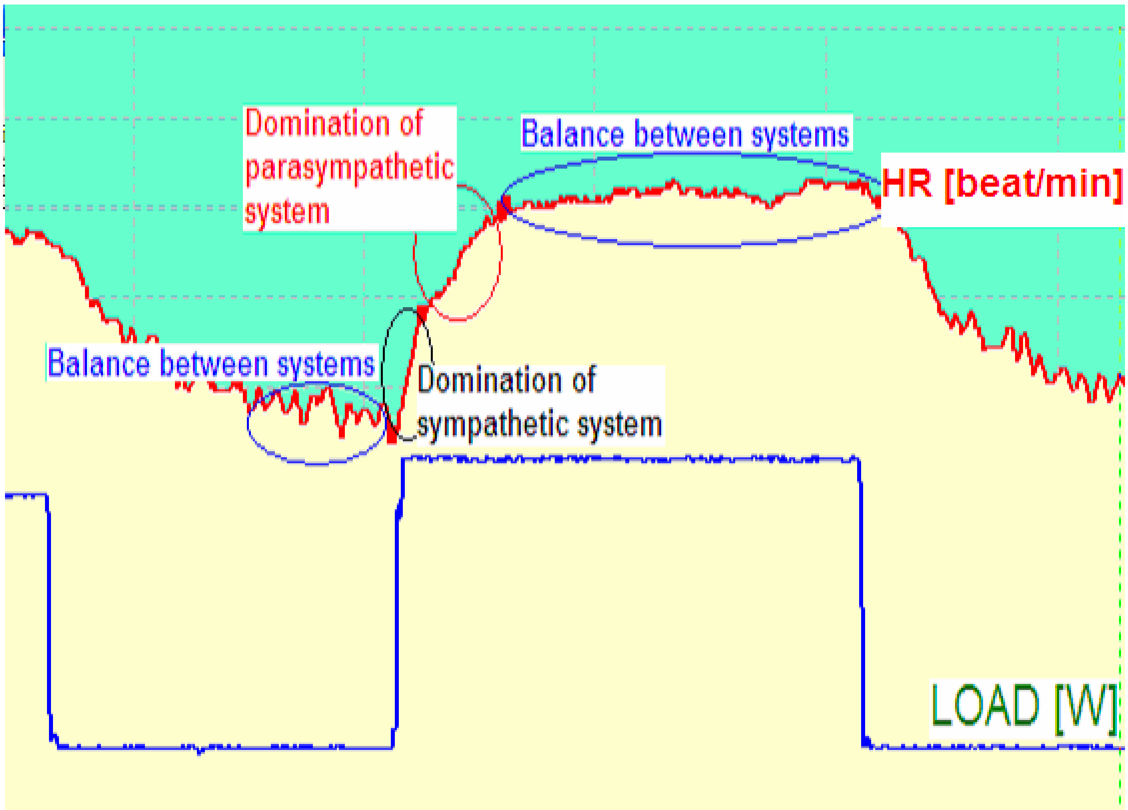
General idea of steady state HR model.

In such a model the competition phenomena between parasympathetic and sympathetic system was omitted, because when steady state is reached both systems are balanced and it is not possible to find out clearly what system may dominate.

6.2 Investigation of test results – searching for baroreflex activity.

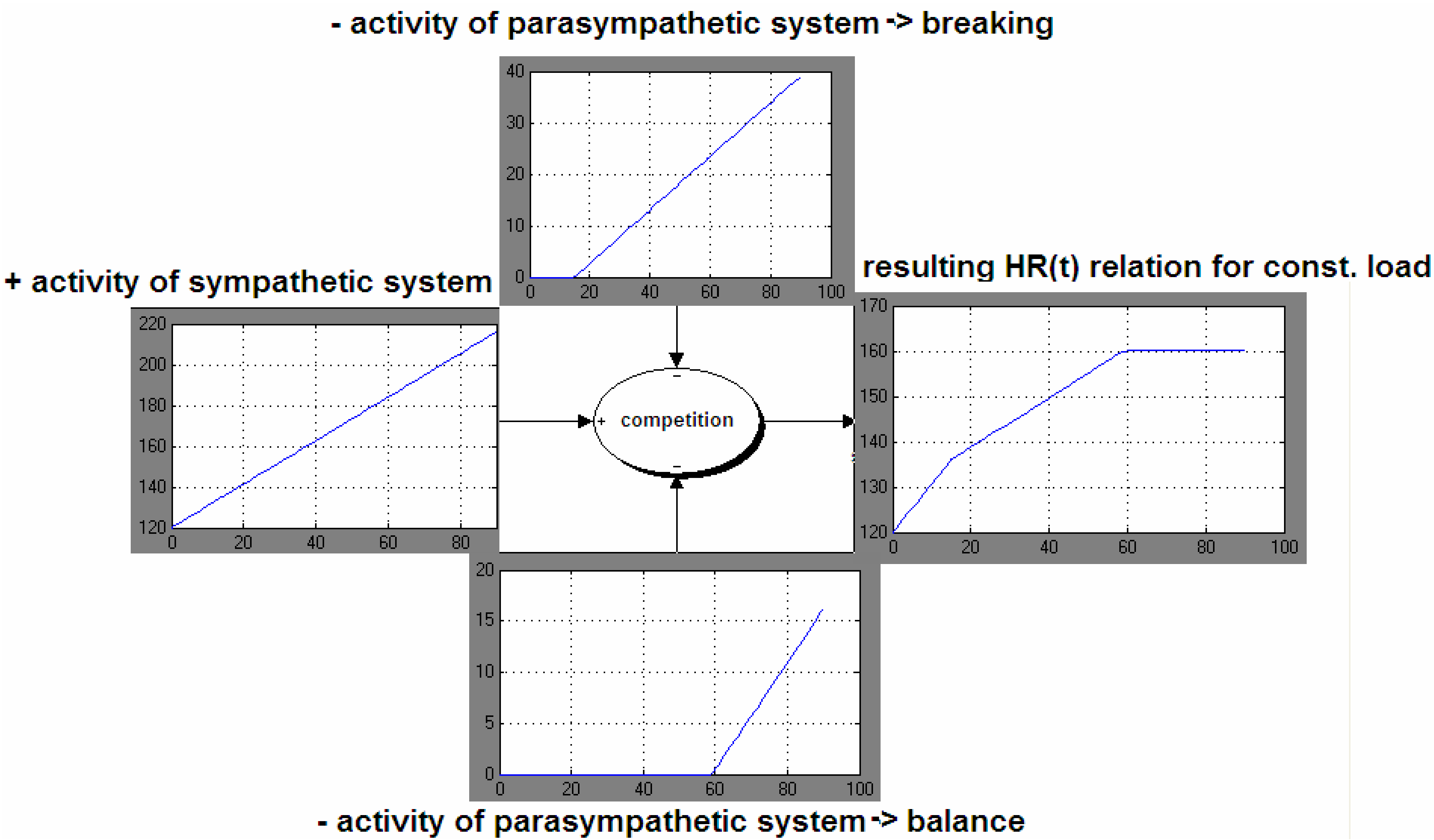
The next challenge that I have stated was to find a trace of knowledge about physiology concerning baroreflex cardiac control system that might be recognized in data collected during a test.

During the investigation of obtained test results, each response results in some characteristic regions, presented below.



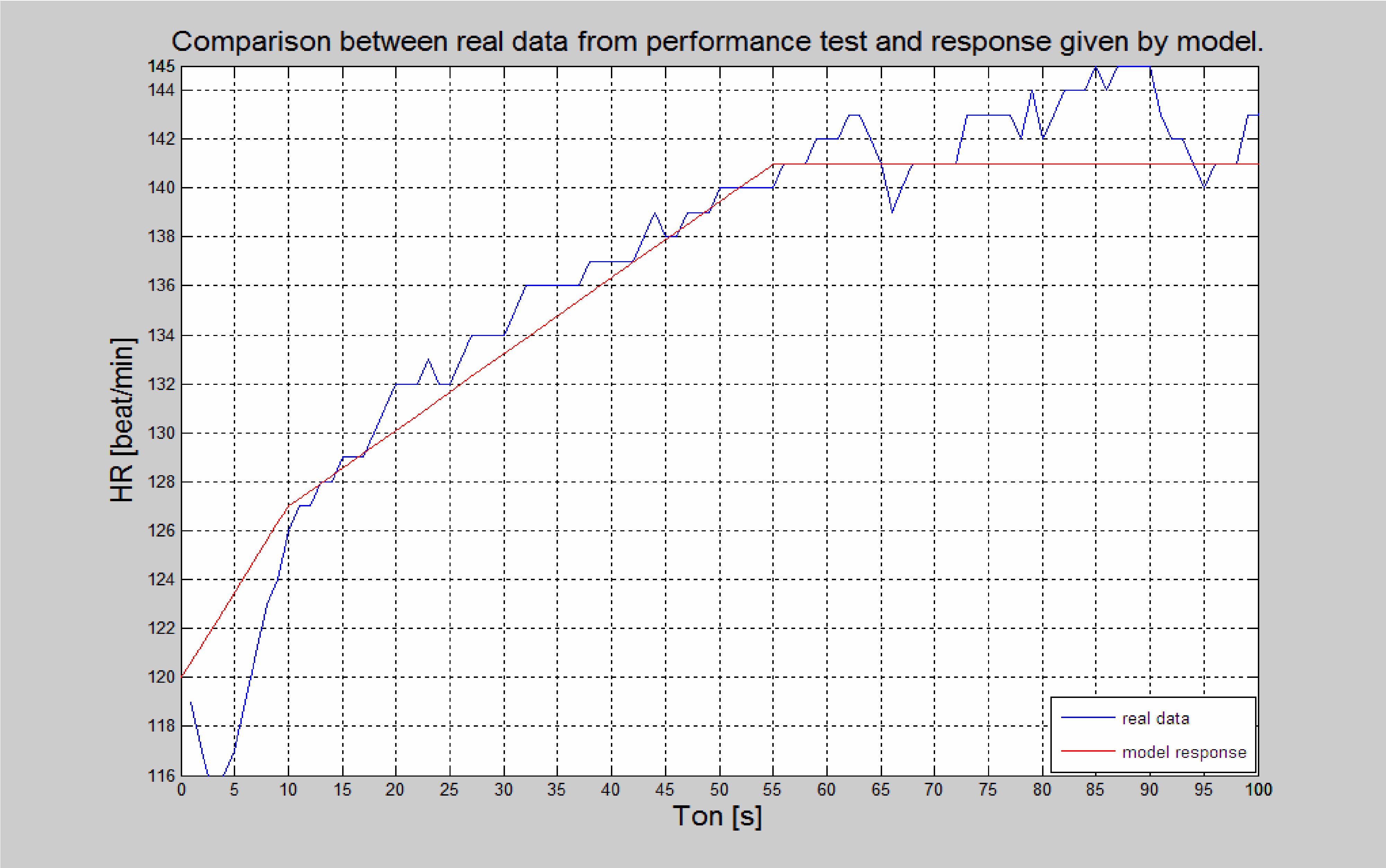
HR response on effort – characteristic regions.

On graphs showing results of carried out experiment, we may distinguish for every applied load 3 kinds of characteristic regions. As it is seen on the picture above, we may assume two regions where balance between influence of sympathetic and parasympathetic system is preserved – it is resulting in HR steady state. In the initial moment where the load is applied, a linear jump of heart rate is visible – we may conclude that sympathetic system dominates the parasympathetic one. When relation looses its linear character, “breaking” is initiated – we may observe influence of parasympathetic system that becomes dominant until a balance is established.



Brief description of how does the model work.

6.8 Results concerning dynamics of baroreflex system (first 100 seconds of effort duration).



Comparison between modeled baroreflex response and real data for load 200W.

8. Literature.

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