Magnetic Levitation Control

Magnetic Levitation Control (MagLev) is a specialized software for a control of magnetic levitation process on Magnetic Levitation equipment Model CE152 created by HUMUSOFT. The procedure is based on inaccurate description of the situation using the language formulated by fuzzy IF-THEN rules (rule base). This design allows to control the process without knowledge of its exact mathematical model and physical constants of equipment. Only the rough behaviour of magnetic levitation process. The software uses the computational kernel from software LFLC 2000 and a rule base created in LFLC 2000. Inputs for computation of the action are taken from a PCI card MF624 delivered with the Magnetic Levitation equipment Model CE152.

1 The principle of magnetic levitation process

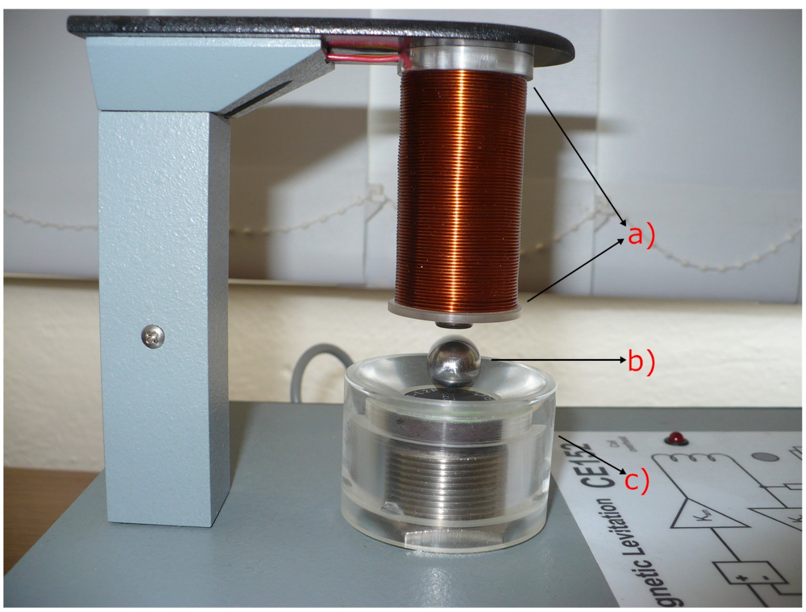

Figure 1: Main part of a device for magnetic levitation

When electric current is passing through the coil with core **a)** there is an electromagnetic field. This electromagnetic field operates on steel ball **b)** and if the field force exceeds the gravitation force, ball is lifted to the core of the coil. If the ball is in motion the kinetic energy of the ball enters the process involved in the direction in which the ball moves. This process is very unstable because once you exceed the force acting upward, the ball starts to move toward the coil, it gets to a stronger electromagnetic field and accelerates to the coil. Similarly, the ball accelerates downward if the gravity force becames stronger. Ball position is read by sensor **c)**. The process control is performed by changing the input voltage applied to the circuit with coil.

2 Fuzzy IF-THEN rules with linguistic variables

An example of fuzzy IF-THEN rules with linguistic variables:

Rule by words:

IF ball position is close over AND its speed is small down THEN raise the voltage a bit

The same rule symbolically in LFLC 2000:

IF E is +sm AND dE is -sm THEN dU is +ve sm

The vague terms "close over", "small down" and "raise a bit" are so called evaluative linguistic expressions. Their meaning is modelled by (context-dependent) fuzzy sets and the whole system of assigning appropriate fuzzy sets to given linguistic expresions is implemented in LFLC 2000.

This approach allows the identification of rules by a user who has no knowledge of fuzzy sets.

3 Use of software MagLev

The first step is the choice of rule base. You can use testing base "test_ML.rb", or create your own in LFLC 2000. For loading a rule base click on **d)** *Load...* (Figure 3).

Next, select the time delay between actions **g)** (Figure 3). The maximum delay between the actions for which this process can be controlled is $1ms$.

In the case of using another rule base, contexts variables must be properly set up **f)** (Figure 3) (What you mean by the words "big", "small" in the case of individual variables).

For example, if the context of deviation from the desired position E place 3 it means that all values of $E \geq 0.94 * 3$ will be taken as a "big positive" ($+bi$) and for the output behavior is selected rule which has $E = +bi$ in antecedent, the values in the range of $0.94 * 3 > E > 0.44 * 3$ are not certainly big (degree of truth that E is big in this interval decreases to zero), and therefore the rule with antecedent $E = +bi$ can only be applied with lower force, for $E \leq 0.44 * 3$ the rule with antecedent $E = +bi$ is not fired. This is because of the definition of the expression $+bi$ in 2000 LFLC software where you can also find other standard terms.

These contexts can be set directly within a rule base identification in LFLC 2000. But if we keep the contexts of variables in LFLC 2000 identification set

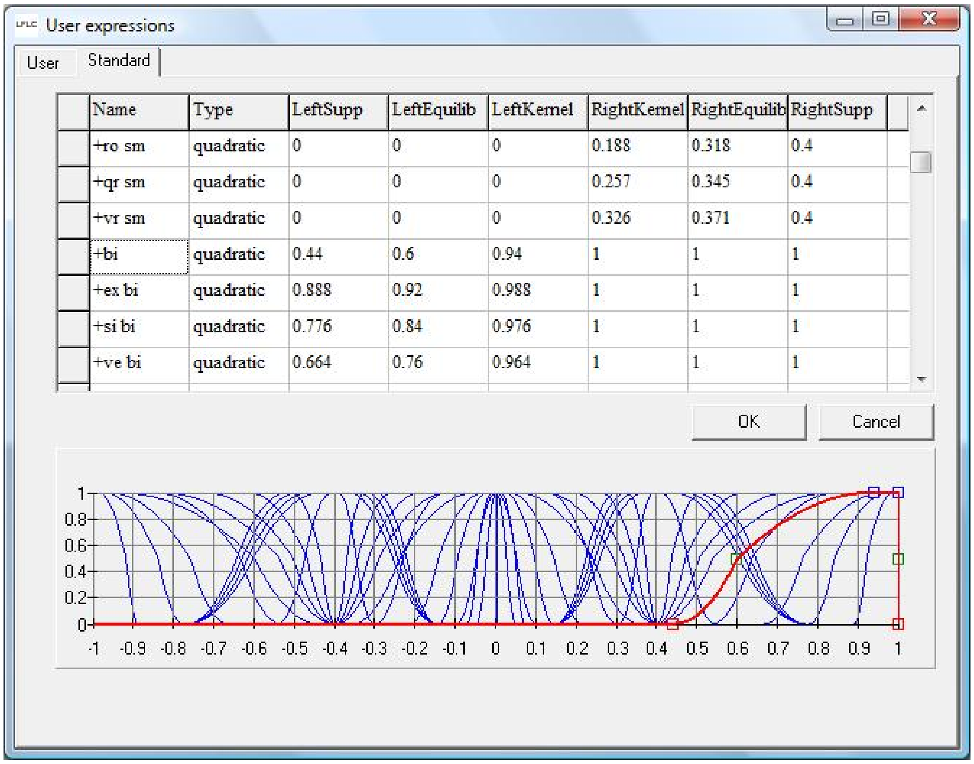

Figure 2: Definition of $+bi$ in softwar LFLC 2000

to standard values $[0, 1]$ or $[-1, 1]$ in our case (all three variables may attain both positive and negative values), and if we identify the contexts of variables in MagLev for our specific case, we will be able to use the same rule base for different processes with a similar behaviour.

Note, that the chosen control action dU is the input voltage difference and hence, it is time delay dependent. Therefore, actions that you will see in the process table **k)** (Figure 4) have size as the context for the dU was multiplied by a time delay in milliseconds. For our test case, this means $1.7 * 0.4 = 0.68$.

The next step is to select the desired position **h)** (Figure 3) of the ball. In this case it is impossible to control the process if you select a position too close to coil! The "test_ML" rule base is set for *Setpoint* around value of 2.

Now, we only have to start the process of magnetic levitation. Click on *Get Ready* **i)** (Figure 3) the button will change to **Start** wait until the steel ball stabilizes under the coil and click on it again, the button will change to *Stop* and ball will levitate in the desired position. If you are not satisfied with it click the *Stop* button, look at the position of an inappropriate behaviour of the ball and read the numbers of rulls which were fired. Then change them as necessary and start the process again. Improving the control can be achieved also by a minor change of any context.

4 Description of MagLev application window

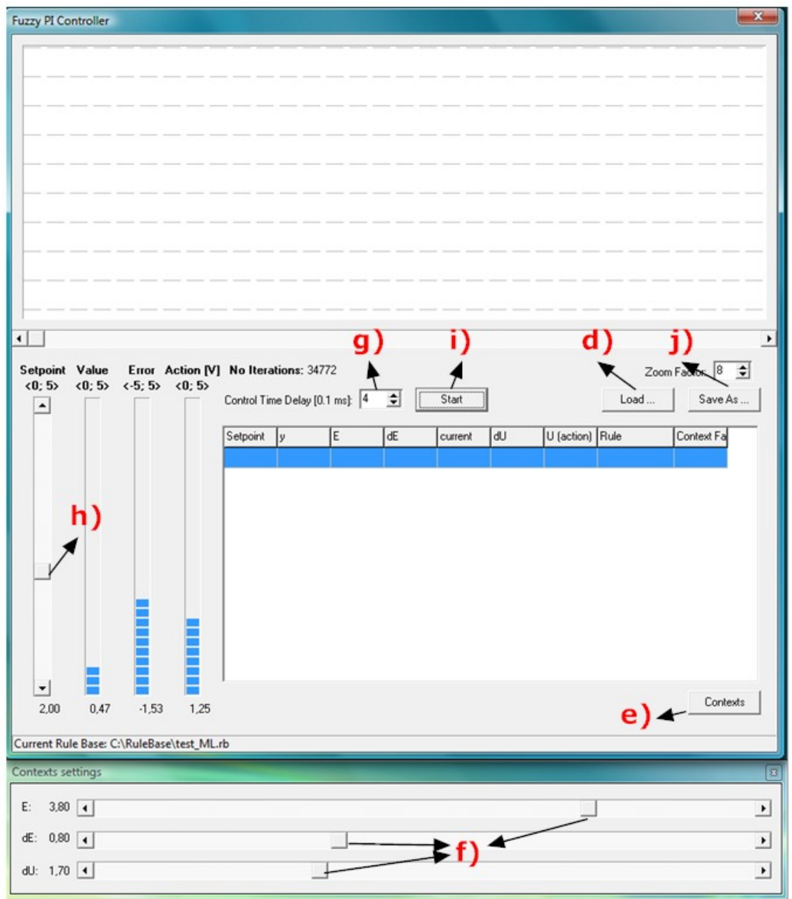

Figure 3: MagLev application window before starting process

- **d)** Button *Load ...* used to retrieve the rule base
- **e)** Button *Context* opens the contexts window **f)**
- **f)** Contexts window - Possibility of changing the setting of contexts for individual variables
- **g)** Time delay between actions

- **h)** Possibility to set the desired position of steel ball
- **i)** Button *Get Ready/Start/Stop* used to start and stop for process
- **j)** Button *Save As ...* used to save the current settings, including the table of values **k)** from latest process

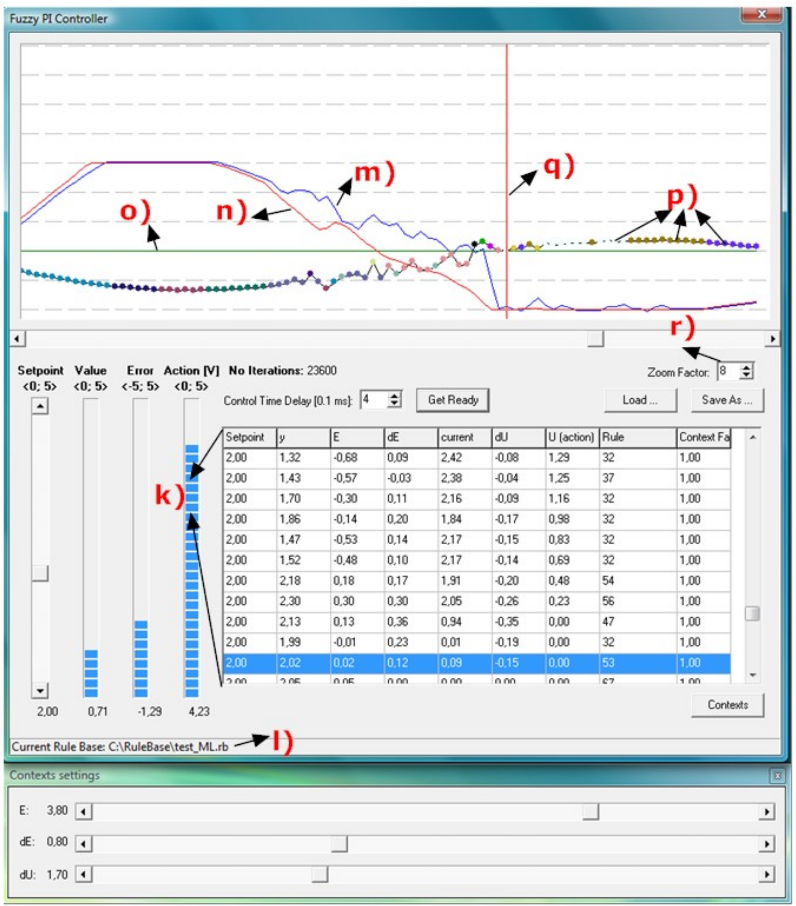

Figure 4: MagLev application window after end of process

- **k)** Table of values measured and calculated during the process control. *Set Point*: desired position of ball; y: the current position of ball; E: deviation from the desired position, dE: Speed of the ball (difference between the average position of balls in the previous six measurements and average position in the two previous measurements and the current position), *current*: electric current in the coil; dU: change of the action of the intervention (how much we raise or lower the voltage), U(action): the size of the incoming voltage, the control variable; *Rule*: number of the fired rule, *Context Factor*: Only in case of a change in the context during the process

- **l)** Computer address of currently used rule base
- **m)** Electric current curve (blue)
- **n)** Voltage curve (red)
- **o)** Desired position of the steel ball (green)
- **p)** Ball position in the individual measurements, different colors represent different fired rules
- **q)** Pointer which point to the place in the graph corresponding to the highlighted row in the table of values **k)**
- **r)** Graph zoom