Remote Lab Experiment RC Oscillator for Learning of Control

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Abstract—**In the paper a remote lab experiment RC oscillator used to support Web based learning, to support learning by doing, to learn control design and to minimize the gap between theory and practice is presented. The experiment was designed with a special care for visualisation of important control design parameters in Bode plot and Root-Locus diagram. The experiment is based on MATLAB, LABview and DSP2 learning module. Using RC oscillator experiment RC circuit step response based or sinusoidal response based analysis, P controller design using Bode plot or Root-locus, relations between control design parameters and control performance and discrepancy between theory and practice could be covered. A homework based on RC oscillator experiment is presented and obtained experiences are discussed.**

Index Terms— **Gap between theory and practice, Learning by doing, Remote lab, visualization of control design parameters.**

I. Introduction

The Internet (Web) has become a widespread tool for teaching and learning. The Web enables more flexible delivery (anytime), distance education (anyplace), new visualization possibilities (interactivity), and cost reduction. Virtual and remote web-based laboratories [1, 2] have been developed up to date. A remote lab at Faculty of Electrical Engineering and Computer Science, University of Maribor was established in order to support learning of control. This remote lab provides various remote experiments (cascade control of DC motor, two axes mechatronic device control, RC oscillator). Remote lab experiments are available on the Web address: http://remotelab.ro.feri.uni-mb.si/eng/experiments.asp.

In the paper the remote lab experiment RC oscillator supporting the learning of control theory and control design is represented. For RC oscillator controller design, a visualization of controller design parameters is implemented interactively with the remote control experiment.

The RC oscillator is a web-based interactive controller design experiment (in the following WICDE). The RC oscillator experiment is used in an introductory control course at our faculty. The objectives of WICDE are:

- to teach students control design,
- to minimize the gap between control theory and practice, by teaching control implementation [5, preface],
- to show students how to learn by Web and how to use it and
- to support learning by doing.

The WICDE was designed to be available to a broad range of our students. Therefore, it was designed with minimum software requirements from the students prospective. To perform the WICDE experiment, a standard web browser (Internet Explorer, Mozilla, etc.) and 'LabVIEW Run Time Engine' are needed. Unfortunately, the assumption of minimum student's software requirements sets an undesirable limitation on the implementation of 'Learning by doing'. This limitation means that students can not build their own experiment but could only vary the parameters of the already prepared experiment. Such a limitation is widely accepted for web-based experiments. Only a web-based experiment presented in [3] assumes the MATLAB/Simulink software environment to be possessed by the students. Therefore, in the case of the web-based experiment in [3], students could build their own experiment from home.

II. System Architecture of WICDE

WICDE is implemented using a DSP-2 learning module, and a breadboard with an RC circuit (Figure 1). The DSP-2 learning module is an 'embedded', light, small in volume and versatile DSP2-based control system. It was developed at the Faculty of Electrical Engineering and Computer Science, University of Maribor. The same DSP-2 learning module could be used for various laboratory experiments (RC oscillator, DC motor speed/position control, buck converter control, etc.) at the site as well as for the remote lab experiments because its interface card is exchangeable. The DSP-2 learning module is presented in detail on the Internet address: http://www.ro.feri.uni-mb.si/projekti/dsp2.

The DSP-2 learning module represents an open framework for rapid control prototyping (RCP) and rapid remote control experiment development. Figure 2 presents the block scheme of the DSP-2 learning module-based remote laboratory. A DSP-2 learning module, connected to a lab PC through the serial port, implements a control algorithm developed using MATLAB/Simulink [6], and through the analog and digital I/O signals, drive the real plant. LabVIEW virtual instrument and the LabVIEW server run on the same lab PC for the purpose of enabling remote control of the real plant.

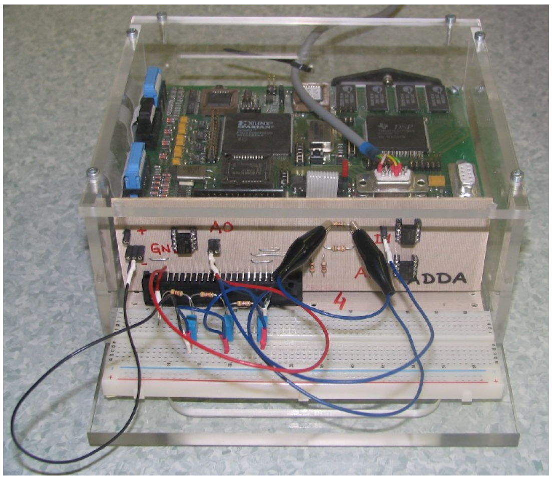
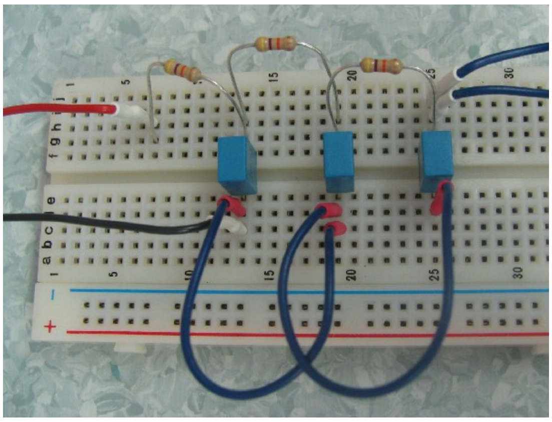

Figure 1. DSP-2 learning module with RC circuit on the breadboard(left) and RC circuit enlarged(right)

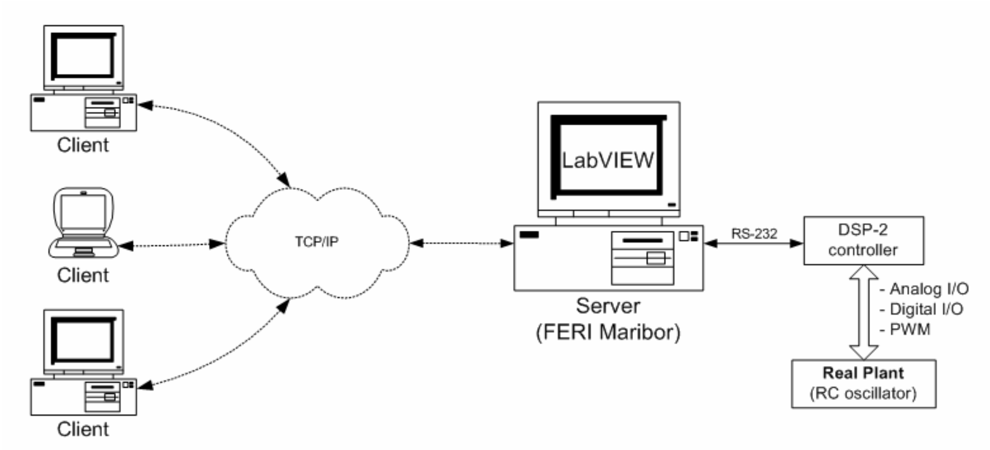

Figure 2. DSP-2 based remote laboratory block scheme

LabVIEW VI performs communication between the lab PC and the DSP-2 learning module, and enables DSP-2 data visualization and parameter tuning, while LabVIEW server enables remote operation of the LabVIEW VI. Remote users, connected to the server through the Internet, must have a 'LabVIEW Run-Time Engine' installed on their personal computer in order to perform remote experiments. During remote experimentation, the remote user can adjust the controller parameters and send experimental results via email.

The DSP-2 learning module-based RCP system is based on two commercially available software packages i.e. MATLAB/Simulink and LabVIEW, and custom-made hardware i.e. DSP-2 learning module. MATLAB, Simulink and Real-Time Workshop (RTW) are used for control algorithm development, simulation, offline analysis and rapid executable code generation [6], while the LabVIEW provides on-the-fly data visualization and parameter tuning tasks. LabVIEW virtual instrument (VI) is automatically generated during the binary code generation process, from Simulink model, where the user front end of created VI depends on special DSP-2 blocks used in the Simulink model. Using Remote Panels (LabVIEW add-on toolkit), generated VI's can be easily viewed and controlled over the Internet. LabVIEW VI's can be published on the Internet with no additional programming and can be remotely observed or controlled by using only the standard web browser.

III. EXPERIMENT RC OSCILLATOR

RC oscillator experiment is implemented using a DSP-2 learning module, ADDA interface card and a breadboard with an RC circuit shown in Figure 1. A MATLAB/Simulink library of blocks (sampling time 200μs) was created especially for the RC experiment. The resistor and capacitor values of the RC circuit are:

- R1 = R2 = R3 = R = 47 kΩ,
- C1 = C2 = C3 = C = 1 μF.

Mathematical model (transfer function) of the RC circuit is given by equation (1). The control loop of the RC oscillator is shown in Figure 3. For the WICDE RC oscillator a MATLAB/Simulink scheme was implemented shown in Figure 4.

The open-loop control of the RC circuit and the feedback control of the RC circuit are combined in one Simulink block scheme. Switch S1 is used to select between the open-loop control and the feedback control. When the open-loop control (krmiljenje in Slovene) is selected then switch S2 is used to select the step or the sinusoidal input to the RC circuit.

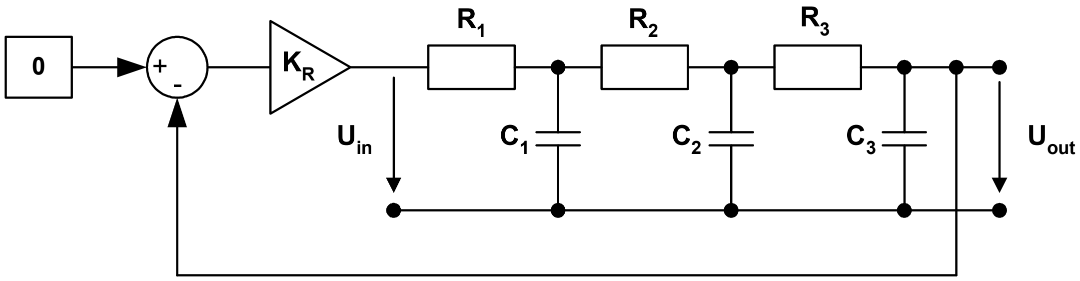

Figure 3. RC oscillator control loop

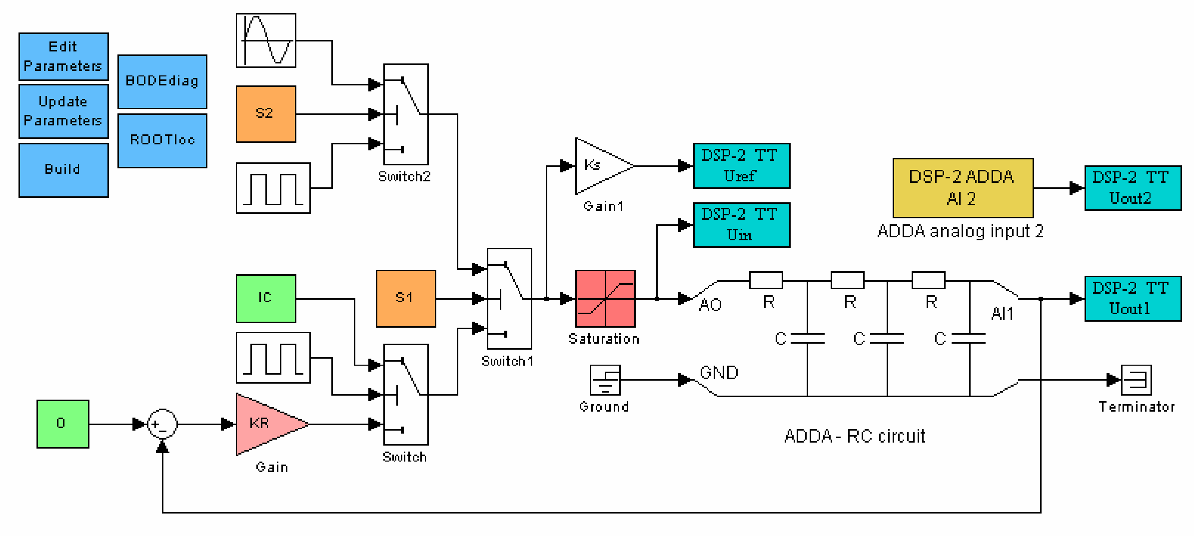

Figure 4. Matlab/Simulink block scheme for RC oscillator

$$F_{RC}(s) = \frac{U_{out}(s)}{U_{in}(s)} =$$

$$= \frac{1}{(R \cdot C)^3 \cdot s^3 + 5 \cdot (R \cdot C)^2 \cdot s^2 + 6 \cdot (R \cdot C) \cdot s + 1} \quad (1)$$

When the feedback control (Regulacija in Slovene) is selected another switch takes action. This switch selects between the initial condition (IC – in Slovene ZACp) input and feedback loop with gain K_R for input into the RC circuit and is triggered automatically by a pulse generator.. Therefore two phases of the RC oscillator response are observed. The capacitors of the RC circuits are charging to the value IC when IC input is selected. This phase is called the ‘charging phase’. In the ‘charging phase’ the RC oscillator output is driven to the value of IC. When feedback with gain K_R is selected the RC oscillator response is observed. This phase is called the ‘RC oscillator relaxation phase’. Now, the steady state of the RC oscillator output is zero, since the desired value for the control loop is zero. Both phases of the response are clearly seen in Fig. 5. Online tuning of the K_R (RC oscillator feedback gain), IC (the value to which capacitors should charge) and per the period of the pulse generator switching between the charging and the relaxation phase is possible. Due to delays appearing in Internet connections, delays appear between the variation of the gain K_R and the interactive view of the RC oscillator response.

A Saturation block was built into the MATLAB/Simulink block scheme of the RC oscillator experiment at the input of the RC circuit in order to visualize the limitation effect of the output port AO.

Signals Uref, Uin, Uout1 and Uout2 could be observed. The signal viewed at Uout1 and Uout2 is the same RC circuit output voltage. The only difference is that sensitivity of the measurement of Uout1 is six times higher than the sensitivity of measurement of Uout2. Observation of Uout2 signal is recommended when open-loop control is selected. The RC oscillator Bode plot or Root-locus plot and RC oscillator response can be observed interactively with a variation of gain KR. Bode plot and Root-locus plot are calculated by MATLAB on the basis of the RC circuit transfer function given in (1). Controller design parameters, such as phase margin and crossover frequency, are clearly marked in the Bode plot (Fig.5). Accordingly in Root Locus the actual roots of the control loop are clearly marked (Fig.6). In this way a good visualization of control design parameters is achieved.. Bode plot or Root Locus design is selected with the left button above the design diagrams in the LabVIEW front panel. It should be noted that no Bode plot or Root Locus appears until the first variation of gain K_R is selected.

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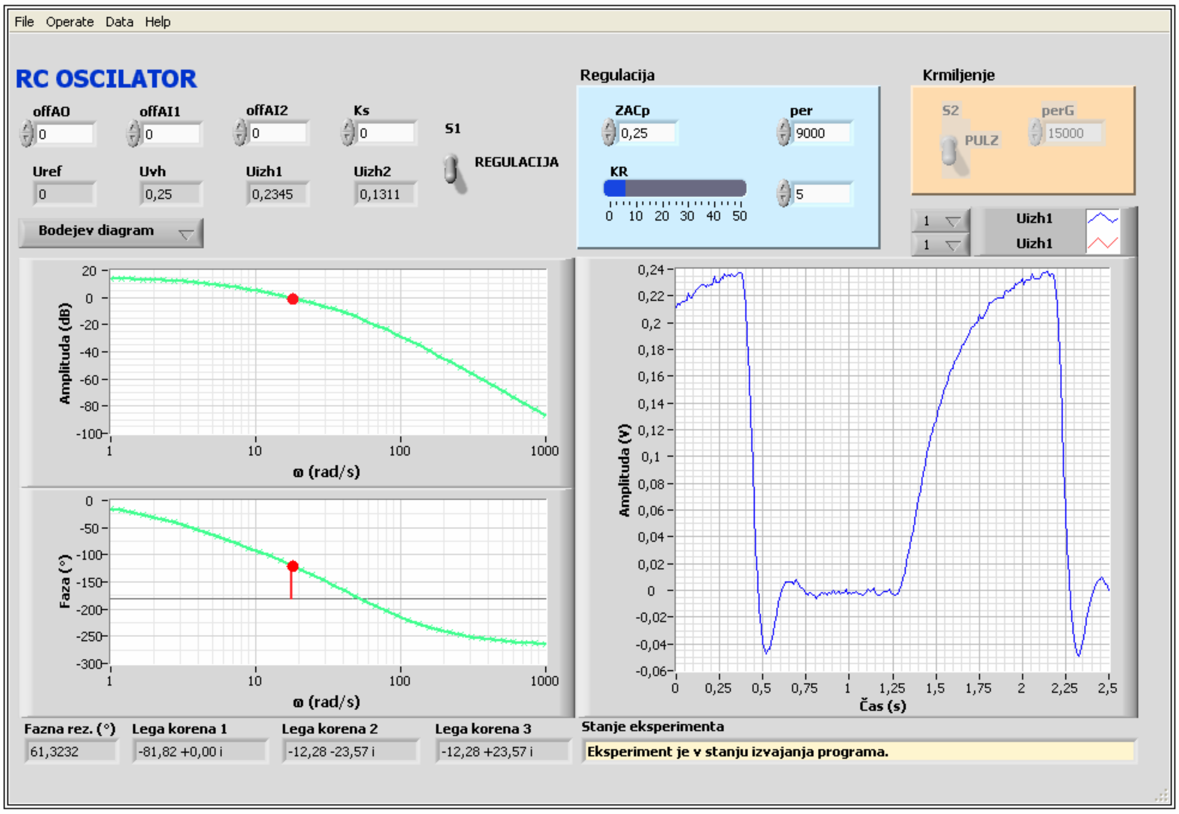

Figure 5. Bode plot (left) with the charging and relaxation part of the RC oscillator response at $K_R = 5$

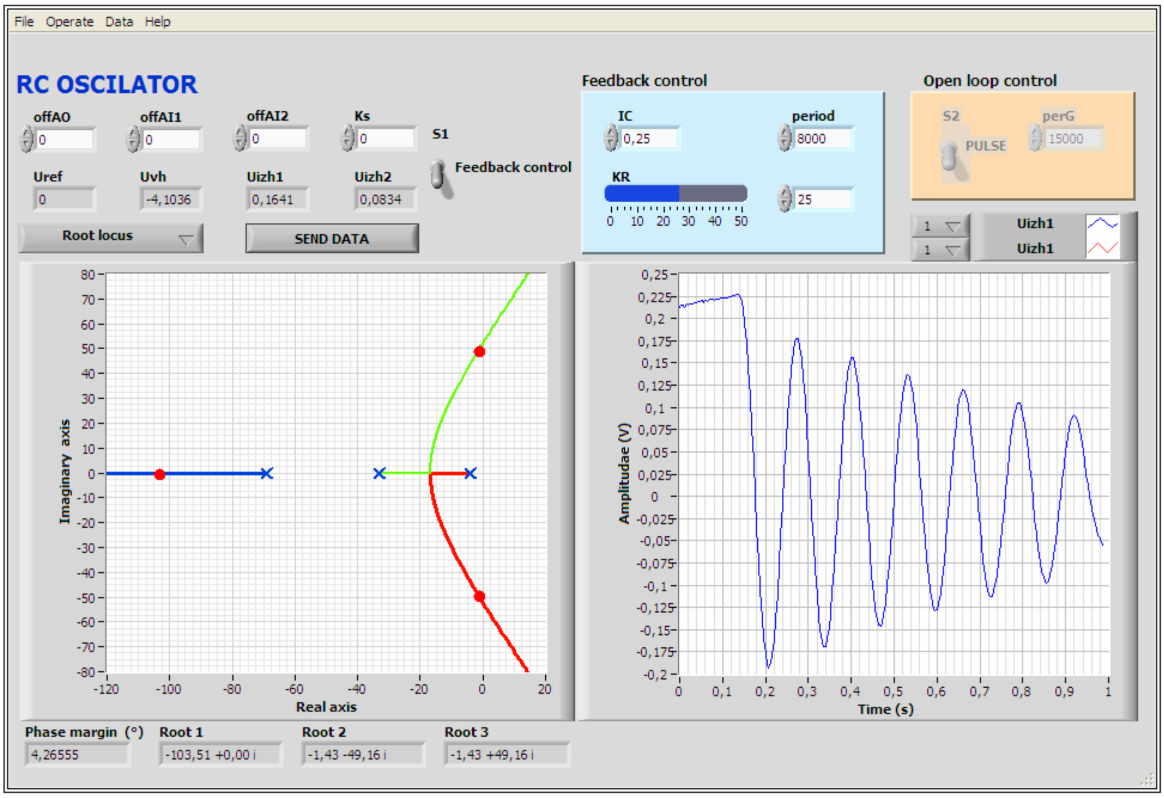

Figure 6. Root Locus method design (left) with only the relaxation part of theRC oscillator response at K_R = 25(right).

IV. Learning control using RC oscillator experiment

Considering learning in the class then WICDE RC oscillator is suitable only as a means for demonstrations done by the lecturer. The reason for this is the limitation of resources (one device – one user) inherently given by every remote experiment. A user could reserve the RC oscillator experiment for one hour. In that hour the user could control the experiment others could only observe the action taking place in the experiment.

WICDE RC oscillator excellently supports individual assignments for students, as is homework, and learning by doing over the web. The main objective of the RC oscillator experiment is to minimize the gap between the theory and practice. Therefore the RC experiment was designed with special care on experimental modelling and exploring the discrepancy between the theory and practice.

Topics that could be covered using the WICDE RC oscillator experiment is:

- RC circuit analysis using step response or sinusoidal response
- P controller design (KR) for RC oscillator using Bode plot or Root-Locus method
- The relation between control design parameters and performance of the control loop step response
- The effect of the initial condition on the RC oscillator
- When and why the discrepancy between the theory and practice appears.

Although P controller is rarely used to control plants and therefore seems to be unimportant in control, it has an important role in experimental modeling and experimental control design, it is in getting “a feeling” for the plant. For instance, identification of control plant is faster and easier using plant open-loop step response than sinusoidal response. The drawback of the control plant identification using plant open-loop step response is that only slow and dominant poles of the plant could be identified. Therefore it is recommended to complement the plant open-loop step response based identification with plant closed-loop identification to identify fast and not dominant poles of the plant. For plant closed-loop identification only P controller is suitable, because it does not affect the phase of the control plant. In experimental control design of PI controller and other controllers it is also recommended to use first in the closed–loop P controller to identify the plant and to get feeling for the actual phase of the plant [5].

Using RC oscillator experiment the discrepancy between the theory and practice could be explored. This discrepancy could be found for higher gains of the control loop. The reason for the discrepancy in RC oscillator control loop is the limitation of the amplitude at the input of the RC circuit. When the signal limitation is in action the linearity of the plant is destroyed and the linear theory used for controller design could not any more accurately predict the behaviour of the closed loop.

In spring semester of the school year 2005/2006 we designed a homework task to be performed using the RC oscillator experiment and assign it to the students enrolled in the introductory control course at our faculty.

A. *Homework 3: RC oscillator analysis*

For homework 3 you should use RC oscillator experiment from the remote laboratory of the institutes of robotics and automation (http://remotelab.ro.feri.uni-mb.si/aboutlab.asp. In addition MATLAB MFILE application or Web SISOtool application of MATLAB Web Server (http://hl1.uni-mb.si/) is needed.

WARNING:

Reserve your RC experiment from the remote laboratory in time! The experiment could be reserved for an hour.

Description of the homework:

Using Bode plot and step response analyse stability of the RC oscillator for gains KR=3.2, KR=10, KR=25 in KR=40. Perform the stability analysis using remote RC oscillator experiment. In order to verify the results of your stability analysis calculate Bode plots and step responses on the basis of RC oscillator model for the same given gains as in experiment using one of the MATLAB Web Server applications. Compare the results obtained from the RC oscillator experiment with the calculated ones. If the differences between the experimental and calculated results appear then check all signals in the remote RC oscillator experiment to find out the cause of the differences and document your findings!

In addition find the gain KR for the margin stability of the RC oscillator by RC oscillator experiment! Check if the same gain KR for the margin stability of the RC oscillator is predicted on the basis of the RC oscillator model.

Find the relation between the phase margin φ_{rez} [^{o}] of the RC oscillator and step response overshoot Apr(%) at various gains KR using remote RC oscillator experiment!

TABLE 1: FILL IN TABLE FOR K_R and PHASE MARGIN

KR	Apr(%)	φ_{rez} [^{o}]
	0	
	.	
	4	
	.	
	16.5	
	.	
	.	
	50	
	.	
	100	

Put the values of corresponding phase margin φ_{rez} [°] and step response overshoot Apr(%) into the table and plot the graphs:

$$\varphi_{rez} = f(Apr(\%))$$
$$Apr(\%) = f(KR).$$

Check if the rule of thumb:

$$\varphi_{rez}\,[°] = 70 - Apr(\%)$$

is fulfilled!

B. *Experiences obtained*

Our students tend to do their homework one day before the deadline. In spite of the warning they did not change their behavior. Therefore it was impossible for them all to finish their homework in time. In the spring semester 17 students were enrolled in the introductory control course, therefore for them all to do the assigned homework 17 hours is needed. After the first deadline was extended they successfully performed the experiment.

Students found no discrepancy between the theory and practice till the gain KR = 40. Fig. 7 and 8 show an example of student results for a case of gain KR = 25 with no discrepancy and KR = 40.with discrepancy. In general the students didn't comment the differences appearing at KR = 40.

Students found a small difference in the gain at margin of stability. In the RC experiment the margin of stability was reached at KR = 27.7, but the margin of stability obtained on the basis of the model was KR = 29.12.

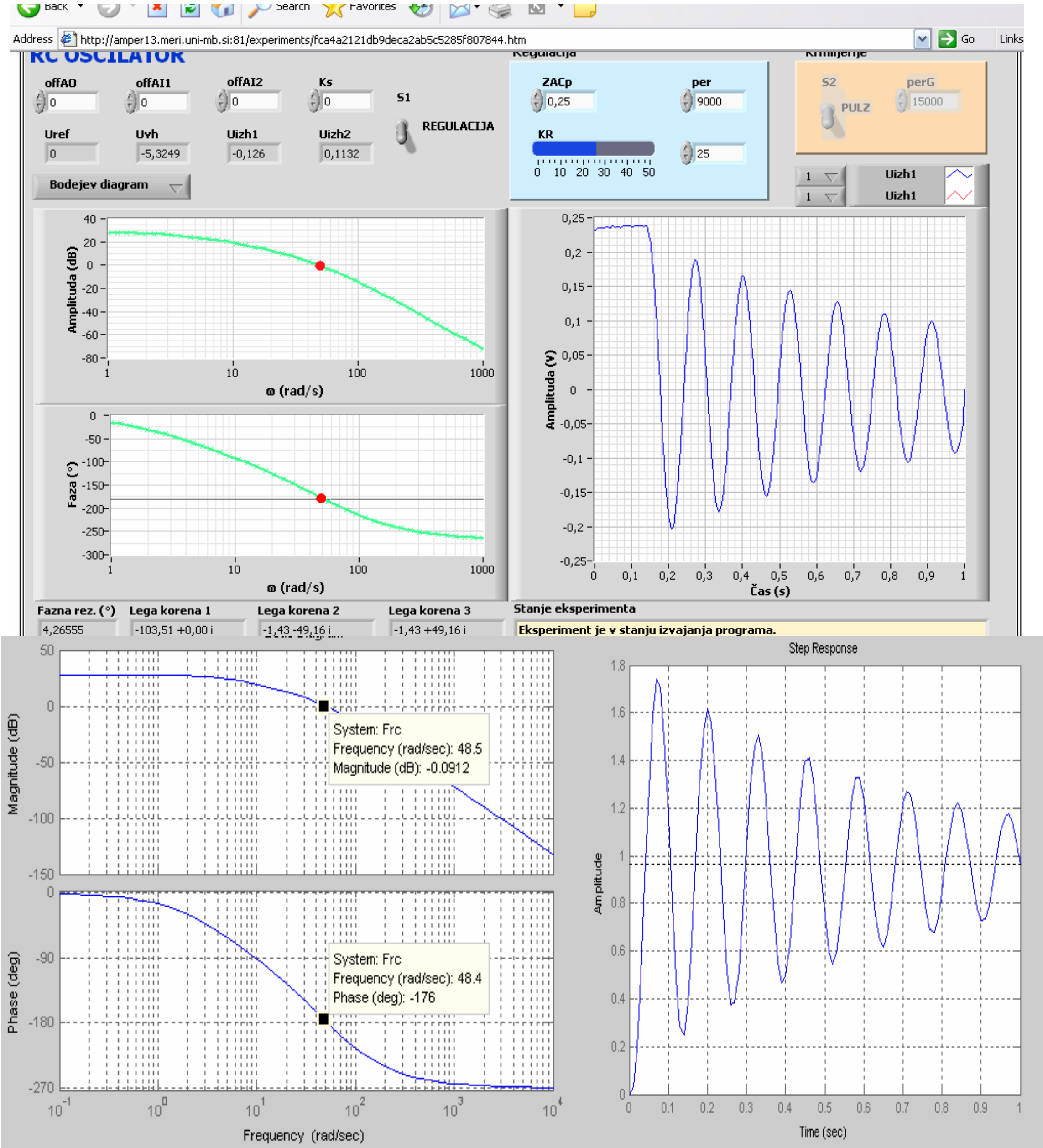

Figure 7. Bode plot and step response obtained with KR = 25 (experimental results are above, calculated in MATLAB from model are below)

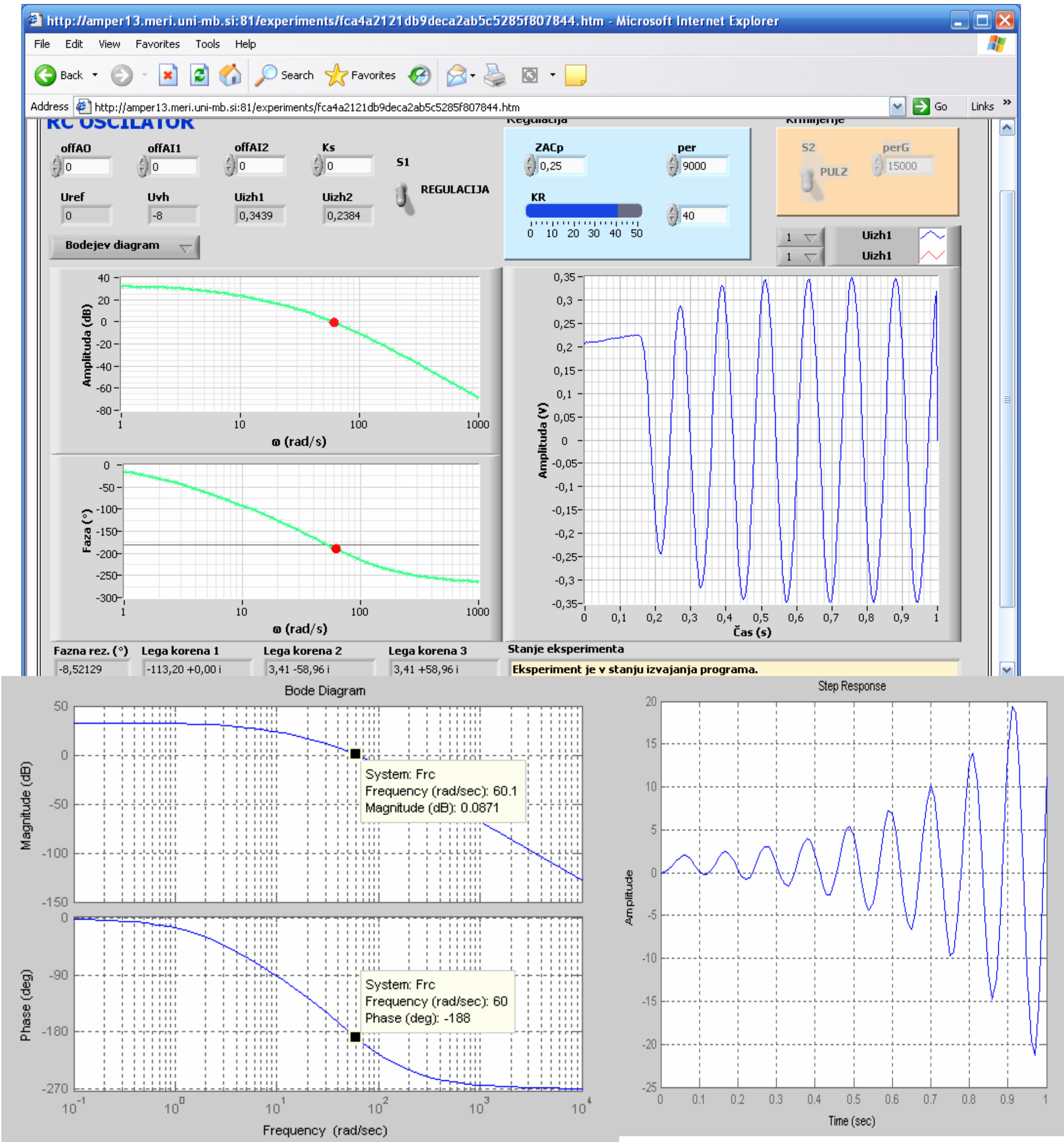

Figure 8. Bode plot and step response obtained with KR = 40, (experimental results are above, calculated in MATLAB from model are below)

Examples of the graphs obtained by students representing the relationship between phase margin φ_{rez} [^{o}] and overshoot Apr(%) and overshoot Apr(%) and gain KR are shown in Fig. 9.

After first organizational problems with access time to the experiment were solved the students were frequently complaining about slow time response of the experiment due to delays in their Internet connections. We hope that in the future better Internet connections would be available.

In addition we found that for each user taking control over the experiment RC oscillator the same initial state of the experiment should be offered. If it were not so, then it often happened that the following student users didn't know how to bring the experiment into the desired state to perform the experiment.

Our students reported about some difficulties because step responses calculated in MATLAB do not exactly match the responses obtained in the experiment. Namely in the RC oscillator experiment the step response goes from some initial value to the steady state zero, while in MATLAB without any modification step responses go from zero to some steady state value. To avoid this problem it might be a good idea to visualize also the overshoot of the RC oscillator step response during the experiment in the future.

V. Conclusion

Using the WICDE RC oscillator experiment our students have the opportunity to learn control design based on real experiments from home for the first time. After first problems with the availability of the experiment were solved the students successfully performed their homework. Performing RC oscillator experiment students got the "feeling" for the actual phase of the RC oscillator and its relation with overshoot of the closed loop. Doing the experiment our students were able to identify when the linear theory does not predict the same results as are obtained from the experiment. It is considered that the RC oscillator experiment successfully supported the student homework. Based on this success a DC motor remote lab experiment with PI controller design to be used for student homework is planned in the near future.

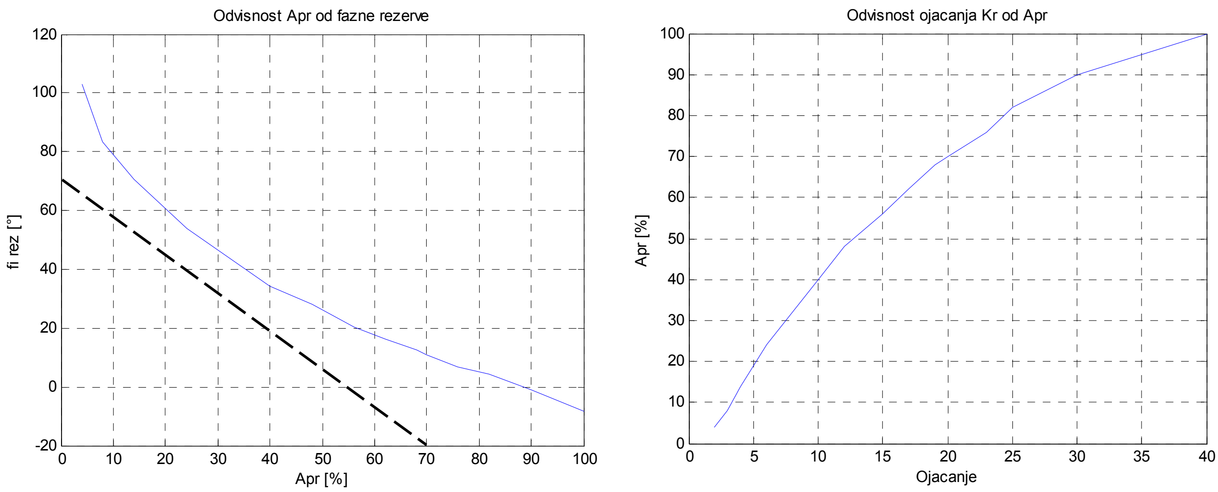

Figure 9. Left graph shows $\varphi_{rez} = f(Apr(\%))$, right graph shows $Apr(\%) = f(KR)$, dotted line shows the rule of thumb

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