# “OPEN-ENDED LABORATORY” METHOD APPLIED IN THE CONCEPTION OF A TEST BENCH TO SIMULATE A DIESEL - ELECTRIC TRANSMISION

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***Abstract*** **–This paper describes the application of a creative method (open-ended laboratory) in a research team work, to create an experimental bench which could be used, with various objectives, in the study of Electrical Machines used in a complex drive system. The paper is structured in two levels: the first level is a review on the creative method of work and the second is the study of the technical problems. The conception of this test bench was made using a new and creative method named “open-ended laboratory” and a modular laboratory of electrical machines. The technical subject of this paper is the synchronous generator as a component in the traction electric system with diesel electric transmission. To make a synthesis of this subject was used the concept of the flow chart, a new interactive mode of thinking in team. In this creative work was used also the brainstorming technique. Concerning the technical problem was studied a lot of literature on the problem of diesel electrical transmission. A complex (technological, materials, engineering and financial) approach is required to solve the arising engineering problems, so, the starting point of this study is the actual context of diesel electrical traction and the constraints imposed to the synchronous generator. Experimental data were recorded with an acquisition board and modeled with LabView.**

***Keywords***: *synchronous generator, open-ended laboratory, brainstorming technique, flowchart, diesel electric traction, test bench.*

## 1. INTRODUCTION

This paper exposes a creative method (master-mind) applied in the areas of electrical machines. It is structured in two parts. In the first part, the paper fits that subject (engineering knowledge) in the situation of actual socio-economic and cultural, characterized by globalization; continuous competition and quick change that encourage our living background and need adapting our society to the demands of tomorrow's world. In this society, based on competition and efficient, it must be the driving force behind all knowledge, fact for which, the EU has proposed as its cardinal purpose to create a knowledge-based society.

Large-scale communication and the progress of a more worldwide economy, will continue to change and to remove the knowledge process and, as a result, the fundamental information used in the educational practice. An actuality of this capability to share information global is that, practically all engineering students in the world are or will be trained using the same sources of study equipment. The answer to the success of the trained students will be: the meshing of scientific and technical knowledge with the skill to think creatively and to discover new concepts speedily. Secondly, and equally imperative, will be the capability to communicate these ideas and concepts fast and professionally. Besides, the quick communication of the new knowledge makes it accessible very fast around the world. As an effect, the engineer must be able to discover and comprehend the new information, evaluate it, and apply this information effectively. So, that is engineering today.

## 2. ABOUT CREATIVE PROCESS

Because the development of general scientific abilities is decisive to enable students of engineering, to successfully handle open-ended real-world tasks in future careers, researchers and educators must invest more in the development of a balanced method of education, such as incorporating more inquiry-based learning that targets both goals [1]. In order to become researchers, educators, and science professionals’, students must understand the fundamental principles of the technical reasoning and the experimental design. So, the educational process must use new and creative method. The creative process involves many conversations about goals and actions to achieve them, conversations with co-creators and colleagues, conversations with oneself. The participants and their language, experience, and values affect the conversations.

### 2.1. Open-ended laboratory

One of these creative methods is open ended laboratory. Open-ended laboratory module can be mostly defined as course where the students are encouraged to design their own experiments or create their own experimental strategy. This method differs from those used in classical laboratory in which the students required to follow a rigid set of experimental guidelines specified elsewhere as in a lab manual, for example.

We can imagine three general areas where a laboratory course group can be made open-ended: 1) the experiment setup itself - case in which the students team / researchers team propose an experimental system to achieve definite goals, 2) the experimental design - where the students decide the scheme to be followed for data collection to accomplish a prescribed goal, given a certain experimental setup, and 3) data analysis and report writing, where the students decide how the data is to be analyzed and reported.

The steps to setup an open-ended lab are:

-a few weeks into the semester, the students are divided into teams of two or three students.

-as a part of a course project, the teams must experiment on a subject interested in, write a report, and present their results to the rest of the class.

-initially, teachers offered suggestions regarding the different experiments on the subject that could be run, different materials that could be used, while also encouraging the students to exercise their creativity in finding test or experiments. The teams were allowed complete freedom in choosing the equipment, experimental parameters, and the data analysis methods.

-teachers generally acted as a consultant, offering hints and suggestions.

### 2.2. Flowcharts in open – ended laboratory training

Flowcharts are one of the most obligatory tools that practicing engineers use to organize large amounts of information. Flowcharts can be useful in assigning and presenting engineering information in an open ended laboratory. Students can practice flowcharts without help or in groups to show processes and help explain open-ended problems.

Some advices to create flowchart as a mind map could be:

- on a landscape blank paper, make a central icon that represents the subject about which you are writing. Recommendations: use at least three colors; keep the height and width of the central image to approx. 2’’ or 5 cm (proportionately larger for bigger paper); allow the image to create its own shape.
- the main attributes (like the chapter headings of a book) around the central subject are place on a line of the same length (thick, curved and organic i.e. like an arm joining the body, or the branch of a tree to the trunk).
- Add a second, third or fourth level of data as thoughts comes to you,
- Use different colors and styles – they can also show connection between branches by using the same color outline.

Literature shows that the students powerfully approved that the flowchart technique was more useful in communicating the aims of the experiment. They could “see more evidently where they were headed”. They felt more convinced doing the experiments since they had a “road map” in front of them. They also found that the flowcharts deeply helped them later while analyzing the data and writing the laboratory report [2].

### 2.3. Brainstorming technique

The brainstorming technique is commonly used in industry and academia to promote participants to produce ideas in an unconstrained mode. In an academic background, brainstorming encourages students to take part actively in idea-generation exercises and experiments settlement of a multi-dimensional advance to analyzing problems or solutions. In the technical area brainstorming was introduced as an efficient method that was developed considering also mental aspects.

## 3. EXPERIMENTAL CONTEXT

To illustrate the approach of a complex subjects in an "open ended" laboratory, we have chosen as an example the theme “Creating a stand bench for the experimental study of a synchronous generator behavior used in electric traction”. The first step was to establish the theoretical context.

In the current state diesel electric traction and power transmission, electric diesel locomotives must meet various conditions:

- Provide permanent changes of traction force to maintain constant to heat engine speed at all regimes of power;
- Traction characteristics of locomotive to be optimal (tensile force depended speed, power and efficiency to be as close to ideal);

-The locomotive to have a large number of characteristics (more levels of power);

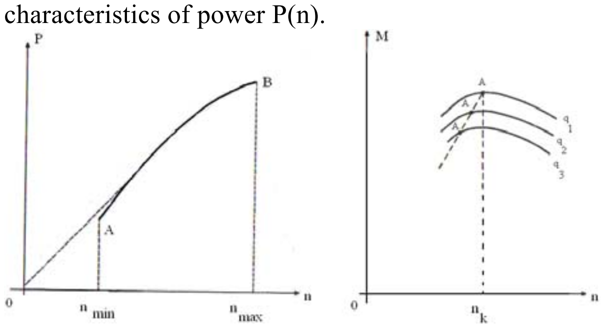
-The locomotive to operate economically, by adjusting the level of injection depending on the adjust of speed (increasing degree of automation), etc..

To study the behavior of the synchronous generator in system diesel engine - synchronous generator is needed to simulate the energy chain that influence, in fact, the choice, design and operation of synchronous generators.

So, the general objective of the experiment is to simulate the transmission diesel engine - generator synchronous. We propose the realization of an experimental bench allowing the study of synchronous generator behavior when the shaft torque is given by an electric machine through which, are modeled the aspects of real diesel engine operation.

### 3.1. The idea of achieving experimental bench

Studying the operation of the system diesel engine – synchronous generator, in specific conditions of electric traction, it appears that, to meet the energy requirements, imposed by the forces needed by traction motor strength, should be made a permanent adjustment of the field current of the synchronous generator.
Starting with this aspect, the characteristics to be drawn in terms of diesel engine, are the families of the mechanical characteristics (power and torque depending on speed) to highlight the level of injection $(q_1 > q_2 > q_3)$ (figure 1) or the characteristics of power P(n).




a b

Figure 1. Mechanical characteristics: a - P (n), of diesel engine; b - M (n) torque depending on speed, highlight the level of injection.

On the studied railway vehicles with thermal engines, source of electricity is the three-phase synchronous generator. For a steady state, characterized by constant speed and constant field current, synchronous generator produces a three-phase power voltage and constant frequency. As these electrical quantities are inadequate electrical traction motors, their processing is necessary to allow adjustment required. This operation is performed by specific static type of traction converters.
Static converters used on diesel vehicles with electric drive are theoretically similar to those used in electric traction. For the synchronous generator the inverter (rectifier) is a heavily distorted source. Power losses in synchronous generator windings depend on the effective values of their cross currents. Since the effective value of these currents is the main parameter in sizing the winding of traction synchronous generators, it is important to determine it.

Therefore, to study synchronous generator it is necessary to plot the characteristics: operating at no load, internal, external, control characteristics and short circuit.

### 3.2. Mathematical background of the idea

It is known that the railway traction synchronous generator works in symmetrical regimes. So, to modeling its operation characteristics we start with the complex equations of the machine, written in the same mode regardless the phase of the analyze [8]:

$$\begin{aligned} \underline{U} &= -\underline{Z}\cdot\underline{I} + \underline{U}_e \\ \underline{U}_e &= -\underline{Z}_m \underline{I}_0 \\ \underline{I} &= \underline{I}_d + K_q\cdot\underline{I}_q + K_E\cdot\underline{I}_E \end{aligned} \quad (1)$$

where the currents are:

$$\begin{aligned} \underline{I}_d &= \frac{I\cdot\sin\psi}{I_E}\cdot\underline{I}_E \\ \underline{I}_q &= -j\cdot\frac{I\cdot\cos\psi}{I_E}\cdot\underline{I}_E \\ \underline{I} &= \underline{I}_d + \underline{I}_q \\ \underline{I}_E &= j\cdot\frac{I_E}{U}\cdot U_e^{j\theta} \end{aligned} \quad (2)$$

and the graphical representation is shown in figure 2:

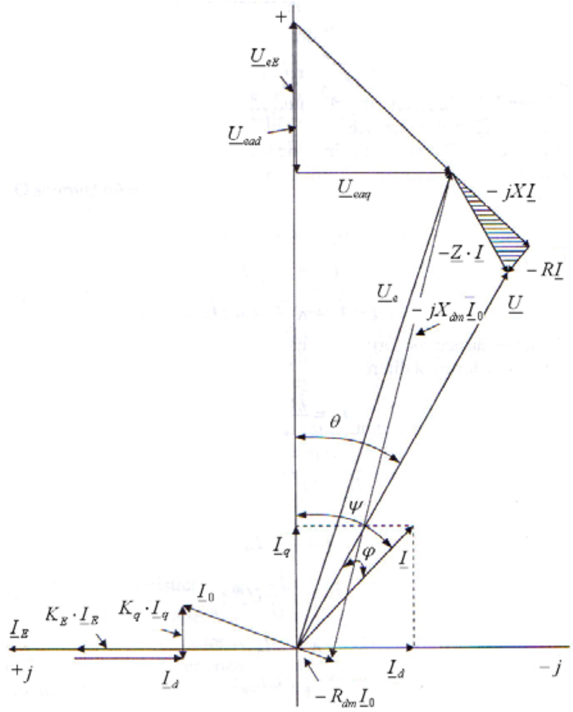



Figure 2. Phase diagram of synchronous generator

To establish the optimal characteristic of the synchronous generator used in railway traction, we start with the diagram of the generator voltage as a function of the field current for different load powers [8]. Technically, this condition must be realized by the injection's system control of the diesel motor and also by the control system of the field current.

Studying the operation of the synchronous generator in common with diesel engine, according with the literature [8], we can say that the generator adjustment could be achieved with its own external characteristics (AEFGD - figure 3), very close to the boundary (ABCD- figure 3).

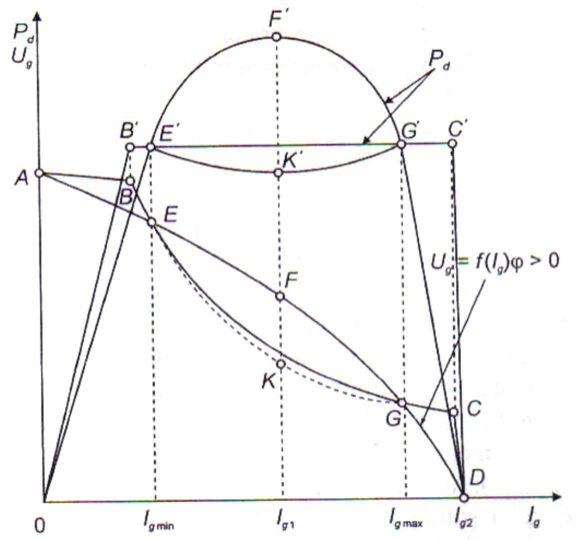



Figure 3. Nominal characteristics of the synchronous generator used in railway traction [8]

The fundamental condition imposed to the excitation system and to the control system is to assure the decrease of the torque of the diesel engine with the speed, following a law of variation close to the curve with the biggest economy of the engine (3):

$$M_e - M_m - M_{aux} = M_g = K_g f_g I_g = f(n) \quad (3)$$

where: $M_e$ - is the effective torque of the diesel engine, [daNm]; $M_m$ - is the torque of the mechanical and magnetic losses, [daNm], $M_{aux}$ - necessary torque for the auxiliary services, [daNm]; $K_g$ - the constant of the generator, $f_g$ - is the magnetic flux of the generator [Wb]; the speed of the group diesel engine – synchronous generator, [min$^{-1}$].

Although the generator works with different speeds between $n_{gmax}$ and $n_{gmin}$, depending on engine speed at each speed is reached to the steady state, speed remains proportional to the frequency generator ($n_g = (60 \cdot f_g)/p_g$). Therefore, the frequency of alternative voltage given by the synchronous generator is changing between the limits $f_{gmin}$, $f_{gmax}$.

In this case, according with the literature [8], the simplified phase diagram of the synchronous generator is shown in figure 4.

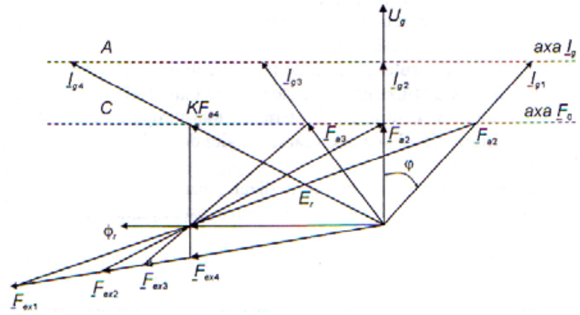



Figure 4. Simplified phase diagram of synchronous generator

Mathematically, the expression of the external characteristic of the synchronous generator is (4):

$$U_{e0} = \frac{U_f^2 + (X_d + X_q)U_f I_f \sin(\varphi) + X_d X_q I_f}{\sqrt{U_f^2 + (X_q U_f)^2 + 2U_f X_q I_f \sin(\varphi)}} \quad (4)$$

### 3.3. Technical solution proposed

The simplest case of electric drive mainly implies the existence of two essential elements of drive: electric machine drive and driven this machine work.

Therefore, we propose a physical system made of two electric machines coupled to the shaft to simulate: one, a diesel engine and the other generator synchronous traction. If the proposed experimental bench the synchronous generator is working machine and drive machine can be a d.c. machine which simulate the functioning of diesel engine.

To track the behavior of synchronous machine operation as a generator under specific conditions of railway electric traction, electric drive chain proposed still requires the presence of:

- a source of DC voltage / rectified, necessary to supply the field winding of synchronous generator;
- a variable load of inductive type;
- a rectifier which is a supply for the load circuit.

a. *Constraints to the drive electric machines to simulate the operation of diesel engine*

Starting from that as the operation under the traction rail diesel engine requires:

- constant power operation at various levels, between rated power and that corresponding no-load;
- operation with constant speed on different output levels, ranging from a minimum ($n_{min}$- proper functioning of the diesel engine no loading) and

maximum ($n_{max}$- proper functioning of the diesel engine rated),
this will be the conditions imposed to the electric machine which simulate the operating as diesel engine.
*b. Constraints imposed to the working machine to simulate the operation of traction synchronous generator*
In the conditions of the generator operating as a part of whole locomotive, the speed of diesel generator group remains constant for a particular system application, but this change with power regime ordered. To achieve the general external operating characteristic, the synchronous traction generator will follow its limiting of voltage and current.

### 3.4. Generate a flowchart for an open – ended laboratory on the subject: "Conception of a test bench to simulate a "diesel electric" transmission"

All those theoretical aspects presented upper are represented, following the steps described in 2.2, in a short way, in the flowchart from the figure 5.

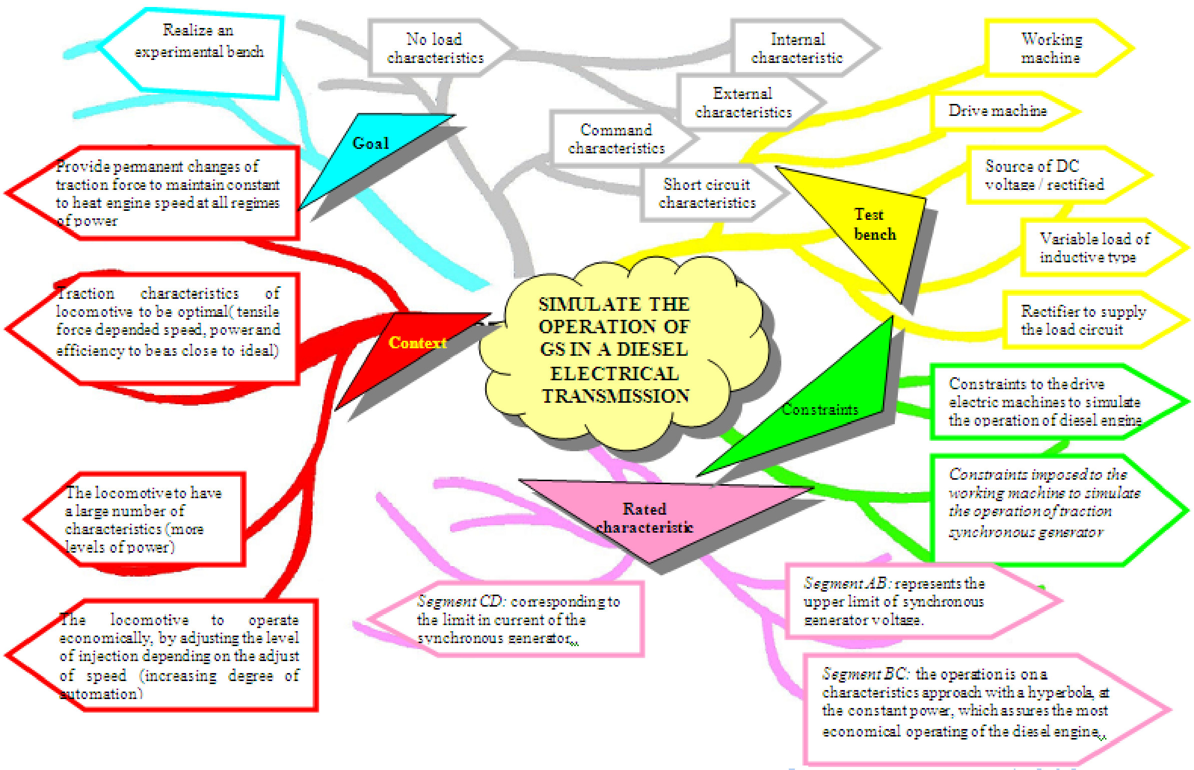



Figure 5. Flowchart of the open ended laboratory

## 4. THE BASIC SCHEME OF THE TEST BENCH

To meet the established constraints (3.3), after a brainstorming session, were used the components of Wuekro stand type teaching, belonging to "Electrical Machines Laboratory" of the Faculty of Electrical Engineering of the " Gh. Asachi Technical University" of Iasi. Stand provides various electrical machines of continuous and alternative current that can be coupled on the same axle with a DC machine that can operate in controlled torque, current or speed from an external central unit.
After a study of the technical characteristics of electric machines stand components were chosen to form the following experimental bench:

- DC machine that can operate in controlled torque, power or speed to be used to drive electric car diesel engine modeling physical;
- salient pole synchronous machine as a physical model of working machine used to simulate the traction synchronous generator.

Synchronous generator, connected to the axle with this machine, will charge through a converter on an inductive load.
In conclusion, because it imposes that the power required by the generator to be as constant regardless of speed or torque required, the characteristics must have a hyperbolic variation (figure 6).
It is considered that this variation is satisfactory when the deviation from constant power level of the diesel engine does not exceed 3% across the range of locomotive speed [5], [6].

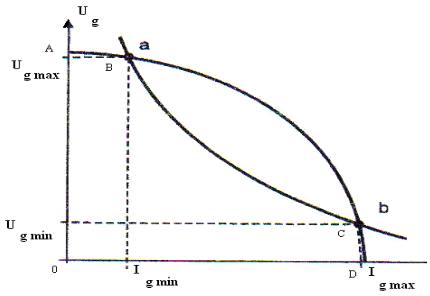



Figure. 6. External ideal characteristic of a tree phase traction synchronous generator

In the operating of synchronous generator traction on external characteristics (figure 5) are distinguished three areas, corresponding to the segments AB, BC, CD:

- *Segment AB:* represents the upper limit of synchronous generator voltage. In this area the required locomotive power decrease, voltage $U_g \approx ct$ and maximum, currents are small and the speed locomotive is maxim.
- *In areas BC,* the operation is on a characteristics approach with a hyperbola, at the constant power, which assures the most economical operating of the diesel engine.
- *Segment CD:* corresponding to the limit in current of the synchronous generator, In this areas, the voltage decrease suddenly, but the high currents, necessary in the starting of the generator, are approximate constantly ($I_g \approx ct$).

In the case of the test bench proposed, the operating machine is a two-apparent pole synchronous generator and the driving machine could be a continuous current machine [7].

As it was shown in flowchart (figure 3), to monitor the synchronous machine behavior during its operation as generator, in conditions specific to a complex process (for instance electric traction) in the electric driving chain proposed, the following are also required:
- a continuous /redressed stress source, necessary for the supply of the synchronous generator excitation;
- a inductive variable load;
- a redresser for supplying the load circuit.

So, to meet the requirements, the test bench consists of a: loading platform; data acquisition and processing system (figure 7).

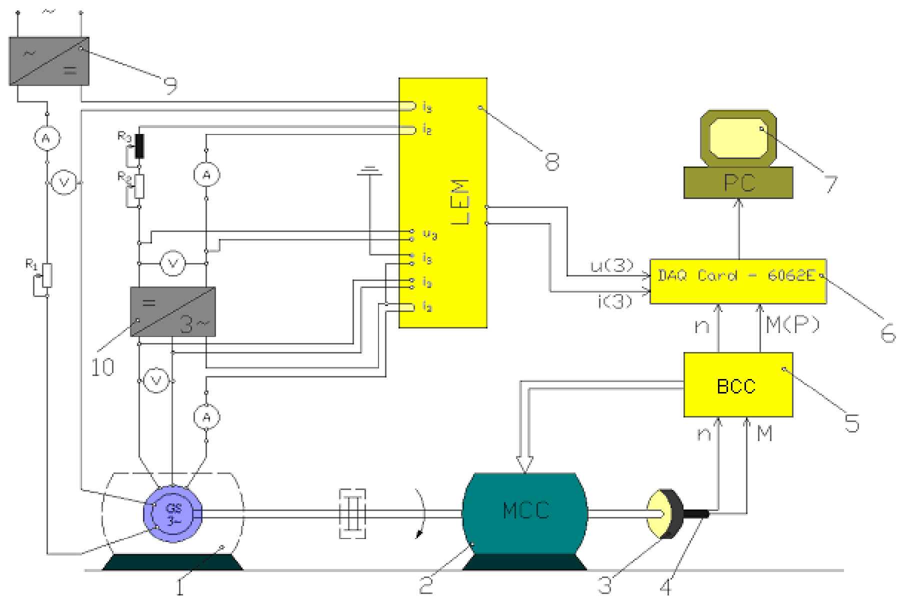



Figure 7. Test bench : 1.- synchronous generator with apparent poles; 2.- continuous current engine; 3.- speed transducer; 4.- torque transducer; 5.- command and control board; 6.- DAQCARD 6062E acquisition plate; 7.- computer for data processing and viewing; 8.- transducers circuit ; 9.- redressed/filtered stress source; 10.- inverter (redresser for supplying the load circuit).

### 4.1. Data acquisition and processing system

Data acquisition and processing system includes transducers blocks for collecting measured parameters, acquisition plate located in a computer and data processing environment for tracing operation characteristics.

#### 4.1.1. Transducers blocks

The measurement of currents and stress necessary for increasing characteristics are performed with *Hall*

*effect transducers* (LEM transducers) that can turn measured sizes in stress included in the range ± *10 Vcc* in order for them to be compatible with the analogical inputs of the acquisition plate.
Also, for the torque measurement, *a tensometric bridge system* was used located under the continuous current machine that provides an analogical signal of ± *10 Vcc*.
In order to measure the speed, *an afterglow diaphragm transducer* was used located on the continuous current machine axle that provides a digital signal converted into an analogical signal of ± *10 Vcc*.
*The acquisition plate* that receives signals from transducers has 8 analogical inputs, a distribution frequency of 200 kHz and is DAQCARD 6024E type, made by National Instruments.

### 4.1.2. LabVIEW data processing environment

To process the experimental data was choose the dedicated software LabView. LabVIEW (*Lab*oratory *V*irtual *I*nstrumentation *E*ngineering *W*orkbench) is a development workbench and environment for the visual programming language from National Instruments. LabVIEW is a graphic programming environment which includes specialized functions for data acquisition, instruments control, and measured data analysis as well as for results display and presentation.

Starting from the specific signals analysis functions to the communication functions with a wide range of equipment, LabVIEW provides everything necessary for developing measurement and test systems, processes control and monitoring systems, scientific research or complex data acquisition.
As in any programming language, solving of a problem starts by establishing the project text with no ambiguities, followed by the enumeration of its objectives.
Objectives establishment, according to the “from top to bottom technique” follows to divide the problem into subproblems, continues with the division of every identified prblem until they are form in indivisible logical blocks.
For the general problem and for any identified sub problem, a flow diagram is made which is the graphic description of data processing flow.
By complying with the general design rules, in the case of experiments proposed, it was possible to achieve structural diagrams for every type of acquisition and type of data processing.
Different functions diagrams have been created. For instance the diagram DGR1 (figure 8) that has the role of collecting and saving the data under the form of text file that can be read with any editing program (Notepad, Word, etc.) has sub-diagrams like: parameters initialization block as well as the real time monitoring panel.

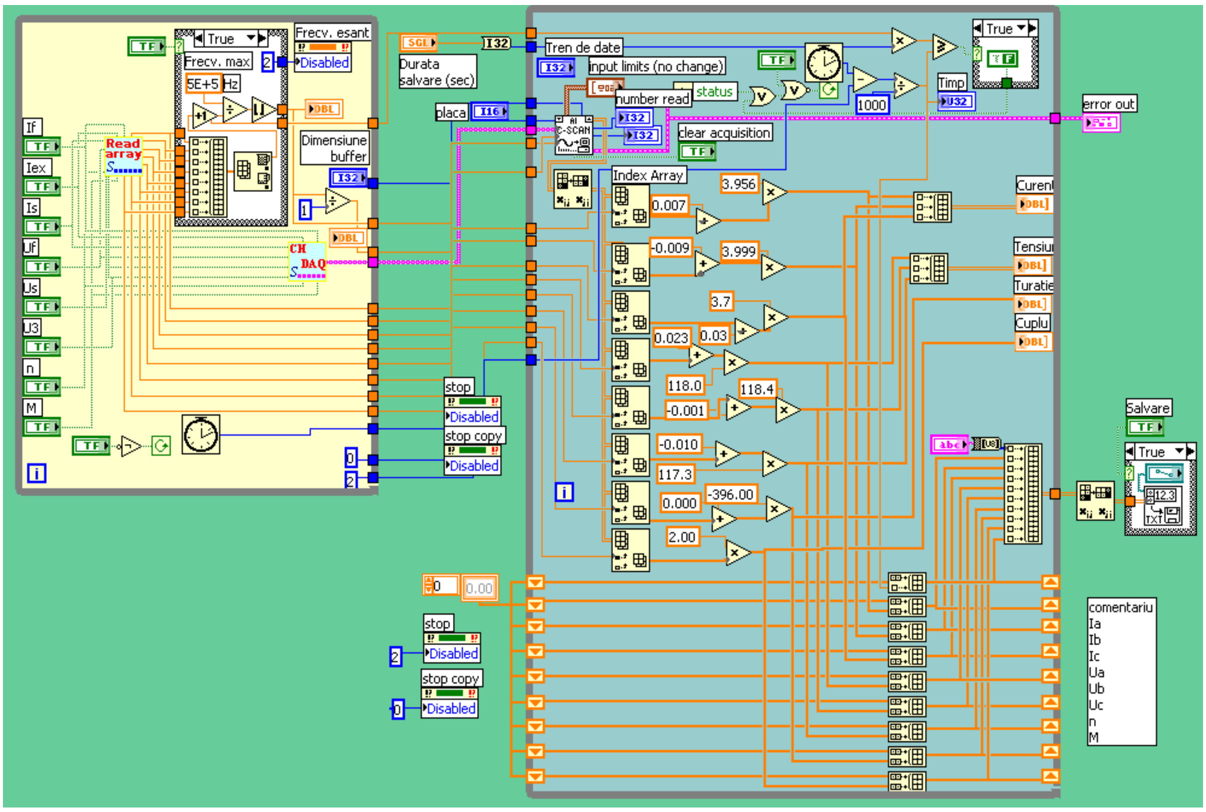



Figure 8. Diagram DGR1

Another category of diagrams are data reading and processing diagrams saved in text files, that can compute other sizes as well and trace the necessary characteristics. They shall be indicated for any class of problems. A detailed example, with a part of the tests made with this test bench and with the final results obtain after programming in LabView, was presented in [7].

### 4.2. Experimental results

The experiment has a great number of aims.
As a response to all constraints presented in theory, first aim of the experiment was to approximate the rated characteristic of the synchronous generator with following tests:
- Segment AB could be obtained with a command characteristics of the synchronous generator $I_g(I_e)|U_g = ct$.
- Segment BC is given by the external characteristics of the synchronous generator $U_g(I_g)|I_e = ct$.
- Segment CD is equivalent with internal characteristics of the synchronous generator $U_g(I_e)|I_g = ct$.

All this segments could be unified in a global rated characteristic of the synchronous generator.
An other goal was to obtain the family of external characteristics at constant speed and different currents of field. For this, the d.c. machine was controlled in speed (with constant speed on power levels) and were made data acquisition for different values of current field.
Were made data acquisitions for different values of currents of field (0,2 A; 0,3 A; 0,4 A; 0,5 A; 0,6 A) at the constant speed of 1500 rpm. After LabView processing's was plotted the family of external characteristics U(I) for n=ct and different values of the current of field (figure 9).

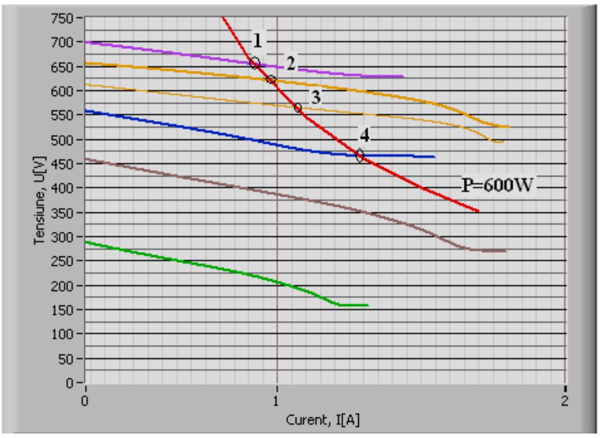



Fig. 10. Family of external characteristics and the curve of constant power, P= 600W

To find the values of current of field which approximate the external characteristic of traction synchronous generator, was plotted in LabView, in the same system of axes the curve of constant power (P = 600 W) (figure 9).

## 5. CONCLUSIONS

An open ended lab is a complex creative method because the teams must experiment on a subject interested in, write a report, and present their results to the rest of the class.
The flowcharts deeply helped later while analyzing the data and writing the laboratory report.
Flowchart technique is more useful in communicating the aims of the experiment.
LabView and data acquisition are a permissive method of work to experiment and illustrate in a graphical environment the theoretical an hypothesis on a complex subject.

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