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ABSTRACT

I. INTRODUCTION

In the modern world there is a huge and growing need for energy. As the consumption of power is growing the level of the pollution caused is also reaching large scales and the available resources are diminishing because most of the energy used is gained by burning carbohydrates. We need to look for further possibilities, alternative energy sources to satisfy the demand and to have a cleaner environment. Because this demand has arisen research and development has begun to satisfy this demand with many kind of new ideas and approaches in several fields and applications. We can say that the electrical energy is a special case because of its versatility.

Previously engineers had the idea that high efficiency can only be reached in large power plants generating big power. There is a problem with this, because it needs superheated steam, large pressure and special turbine blades and construction. This is expensive technology, has a long pay-back-time and these circumstances can not be reached in small scale. The technology for small power plants was not yet developed but as it became available the idea of Disperse Power Plants (DPP) spread fast. The advantage of these plants is small size and there is no need to transport and distribute power because the user is nearby. There are also some problems that need to be solved to have practical use of the theory. These problems are for example: static, dynamic stability problems; phase synchronization; cooperation of DPPs …

These systems can be wind powered, solar powered or as in our example can use a microturbine to utilize waste energy. These turbines can also use natural gas, diesel fuel or other kinds of petrol as primary power. We can also use renewable energy sources or waste energy; they are much more environmental friendly.

In gas lines there are parts using high pressure and some parts using smaller pressure. The connection between these two was solved with throttle valves which can be considered as a waste of power. For this pressure reduction we can use a turbine by which we can make use of the energy previously wasted.

II. GENERAL DESCRIPTION OF THE STUDIED SYSTEM

The studied system works with the reduction of pressure of a high pressure gas with a high speed turbine. Using the energy stored in the gas we can generate electric power and feed it back to the utility mains or use it as a stand alone system supplying a load. The simplified block model of the system can be seen on Fig. II-1. In this representation we can see the whole system including controls, supplementary elements, and the three-phase utility.

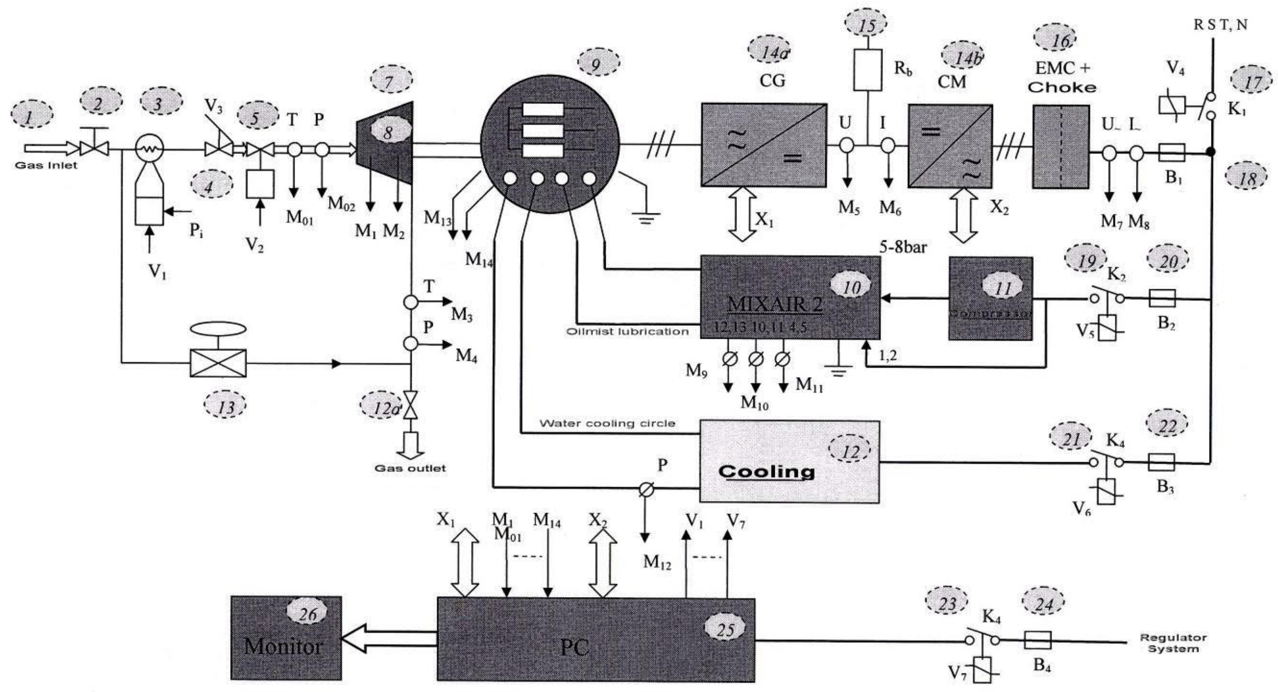

Figure II-1 Block Diagram of System

The system can be divided into two major sections. The first section is the conversion of thermal energy to mechanical energy, and the second is the part converting the received mechanical energy to electrical energy that can be utilized. We can separate also the control of the system as the supervisor of the system. Following the path of the gas then the path of the energy flow the elements and measurement points are introduced. The gas coming in through the inlet (1) has a defined pressure (M_{02}) and temperature (M_{01}), and a given volumetric flow rate. These characteristics can be manipulated according to our needs by heating the gas with the built in electric heater (3), and by using the built in controlled valve (5). The medium flows into the turbine (7) where it expands and the pressure is decreased along with the temperature. (There are some recommendations concerning the outgoing gas quality which we also need to control.) There is a safety path inserted in bypass with the gas line with a throttling valve (13), to ensure the supply of the gas even if, for some reason the generator system is shut down and, the gas flow cannot take the route through the turbine. This can happen due to the malfunction of the turbine, the control or the inverter part of the system. But we have to guarantee that the gas reaches the users. The emergency shut down has a safety valve (4) inserted at the beginning of the turbine branch because the regulating controlled valve is not fast enough for this use.

The turbine shaft is coupled to a generator (9), which is supported by the water cooling system (12), and lubrication system (10) for the bearing of the high speed induction machine. We produce a three phase voltage by the generator. This voltage has a variable frequency and voltage, which is then conditioned by an AC-DC-AC (14) converter. This is necessary because the power supplied by the generator is not suitable to use with usual appliances, which use the voltage and frequency of the mains and also not suitable to be connected to the mains to feed back power. The most important part of the process happens in the converter. The original three phase voltage of the generator is converted to an other three phase voltage having 50 Hz, compatible to be fed back into the mains.

The first step of the conversion is to produce a constant DC voltage. This is done by a three phase diode rectifier (14a). The gained constant voltage can be then converted back to a three phase signal but with a well controlled frequency and voltage. The three

phase signal is obtained by using a PWM controlled inverter (14b).
The system also needs to control the reactive and active power generated from the gas pressure reduction. It is achieved by the correction of the power factor is also possible. The magnitude of the active and reactive powers can be controlled individually by changing the phase position of the converter output voltage vector as compared to the mains voltage vector.
The signals indicated by arrows, marked at various places on the block diagram, are supplied to an industrial computer (25). Using the corresponding interface, the control can be programmed to the wish of the user, of course with some limitations because of the characteristics of the gas pipe lines and the system elements.
Besides the computer controlled safety switches, also relays and fuses are built in to the system to protect the converter part of the system.
As mentioned previously the system can work in parallel with the mains. In addition there is a possibility of Stand Alone Mode (SAM), which means that the generator system is disconnected from the mains and supplies a group of loads by itself. This use is very good in case of power outage or in places where no power lines are in a reachable distance, but gas lines are present.

III. THEORETICAL BACKGROUND

The main requirements against inverters are to produce sinusoidal voltage from the input DC signal. The frequency and the amplitude of the output signal need to be controlled according to the specifications. The output voltage is influenced by the loads on the system.
There is also a requirement against the inverter, which needs it to operate in rectifying mode. So the flow of energy can be two directional. This can be important if we use the inverter as a part of the drive system.
In particular we will be discussing a pulse-width modulated (PWM) voltage source inverter (VSI). The switches are controlled by PWM hence the name of the inverter. The input of the inverter is a constant DC voltage, which is then converted into three phase AC voltage with controlled frequency and amplitude. To be more precise the used method will be sinusoidal carrier wave PWM.

The PWM Switching Method

This method is similar to those of the dc-dc converters but this time it is not utilized to modify the duty ratio of the output but to generate signals for switching. To reach a given frequency, we have a reference sinusoidal wave at the same frequency as desired, and we compare it to a triangular wave. The signals can be seen on Fig. III-1. The triangular wave establishes the inverter switching frequency usually it is kept constant along with its amplitude ($\hat{V}_{tri}$). The output signal of the comparison results in the control signal for the inverter switches.

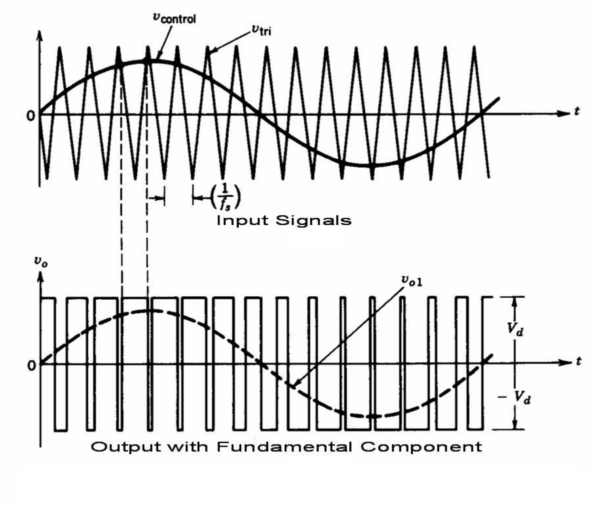

Figure III-1, PWM with Bipolar Voltage Switching

v_{tri}	triangular waveform
f_s	switching / carrier frequency
$v_{control}$	control signal
f_1	modulating/fundamental frequency
m_a	Amplitude modulation ratio

$$m_a = \frac{\hat{V}_{control}}{\hat{V}_{tri}} \quad (3\text{-}1)$$

m_f	Frequency modulation ratio

$$m_f = \frac{f_s}{f_1} \quad (3\text{-}2)$$

The output of the inverter will not be a perfect sinusoidal wave; this means it will contain harmonics as compared to the desired fundamental frequency.

The generated switch control signal will be similar to the output of the inverter because a positive output on the comparison of the input signals will result in a switch position resulting in a positive voltage value. One pair of switches have only two different states because the switches are never off at the same time, this way the output changes between a positive and a negative peak value ($\pm V_d/2$). The resulting outputs fundamental frequency will be the desired and introduced control frequency, with the amplitude derived from the product of the amplitude modulation ratio and the half of the input dc voltage ($m_a * V_d/2$). This can be explained by an example. If we take the original PWM method used in DC-DC converters with a constant control signal, the output voltage average value will be dependent on the amplitude of the triangular wave and the control signal. This can be seen on the figure below (Fig. III-2. a).

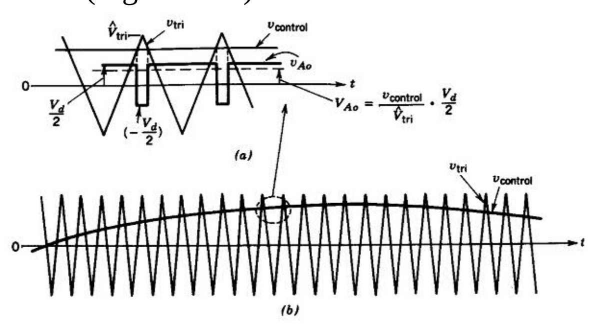

Figure III-2, Sinusoidal PWM

This method is like a very high frequency ratio for a sinusoidal PWM as it can be seen on Fig III-2. b). We can consider the control signal constant for one cycle of the triangular signal thus the average is calculated the same way for one period. This instantaneous average varies as the control signal changes, which is sinusoidal. To put it into a formula as it is pointed out in the figure as well:

$$V_{Ao} = \frac{v_{control}}{\hat{V}_{tri}} \frac{V_d}{2} \quad for \quad v_{control} \le \hat{V}_{tri} \qquad (3\text{-}3)$$

Where, V_{Ao} is the average value of output voltage, for a DC-DC converter.

If we use a sinusoidal control signal the output will be the following:

$$v_{Ao} = \frac{\hat{V}_{control}}{\hat{V}_{tri}} \sin \omega_1 t \frac{V_d}{2} = m_a \sin \omega_1 t \frac{V_d}{2} \quad for\ m_a \le 1$$

Where, v_{Ao} is the sinusoidally varying fundamental frequency component. From this, the peak value of the output sinusoidal component is easily derivable.

$$\hat{V}_{Ao} = m_a \frac{V_d}{2} \qquad (3\text{-}5)$$

This shows that in this range of the amplitude ratio ($m_a \le 1$) the amplitude of the output has a linear relationship with it.

It is important to keep a good frequency and amplitude ratio, because if not selected with proper precautions it can cause unwanted sub harmonics in the output of the system. To be more exact an odd integer number is suggested for the frequency ratio and a small m_a is desired though it is possible to use numbers larger than 1 but it causes an effect called over modulation.

The frequency ratio should be a odd to eliminate the even harmonics from the output this way only the odd harmonics are present. It should also be chosen to be a multiple of three for a three-phase PWM to have these cancellations for all the three phases which are shifted by 120° with respect to each other.

For the technical realization of the system we can use a one legged (half-bridge) or a two legged (full-bridge) construction for single phase inverter. In a three phase inverter we can use three single phase inverters which are shifted 120 degrees in phase with respect to each other. But this is not a common solution because it needs too many switches and it is harder to establish the phase shift. A more general mode to realize this is a three legged construction. The operation is the same as the single phase case concerning each leg.

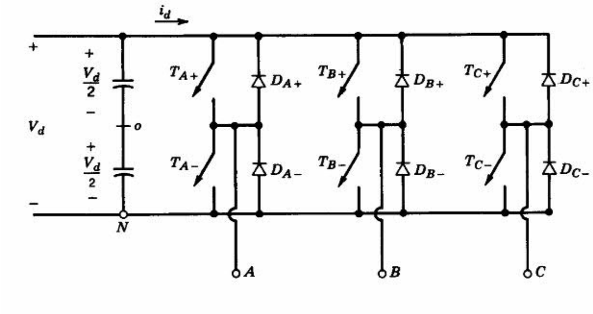

Figure III-3, Three-phase Inverter

In three-phase PWM the same triangular signal is compared to the three sinusoidal control signals that are shifted 120 degrees compared to each other. If we consider a line-to-line voltage the DC components are canceled out in the modulated signals. For a three-phase system only the line-to-line voltages are considered important if we look at the harmonics, because for an individual phase voltage the harmonics look exactly the same as for the single phase system. For a phase voltage this means only the odd harmonics exist as sidebands around the multiples of m_f. Only considering the harmonics at m_f the 120 degree phase difference still exists in the different output legs. This phase difference does not exist if the modulating frequency ratio is a multiple of three, because in this case the phase shifts are tripled which means they are a multiple of 360° thus it looks as 0° phase shift.

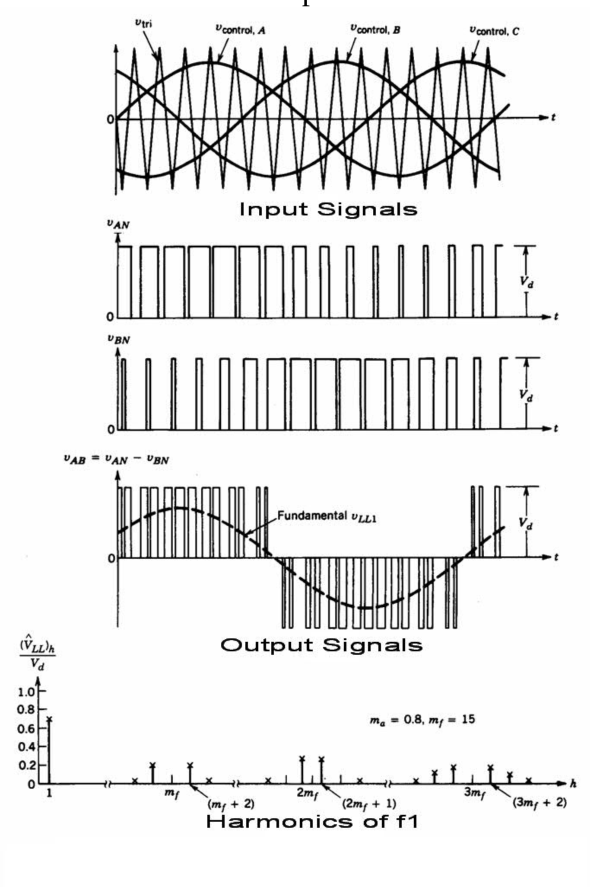

Figure III-4, Three-phase PWM Waveforms and Harmonic Spectrum

The recommendations towards a three phase inverter are the following:

The frequency ratio should be an odd integer for the elimination of even harmonics.

The frequency ratio should be a multiple of three to eliminate the phase shift, canceling out the harmonics in the line-to-line voltage.

If we use asynchronous PWM we should have a large (m_f >21) frequency ratio because this way the amplitude of the harmonics are lowered, but also harmonics appear near 0 which can cause big currents which is undesirable. If over modulated the frequency domain picture of the signal is similar to a low frequency modulation without respect to the frequency ratio.

(Over modulation means that the amplitude ratio is higher than 1)

IV. SIMULATION OF THE THREE-PHASE PWM INVERTER

After understanding the working method of the inverter, it is advisable to start a one phase simulation and compare the results with the ones known from the literature, just to see whether everything is all right. The established one phase system can be seen on the figure below (Fig. IV-1).

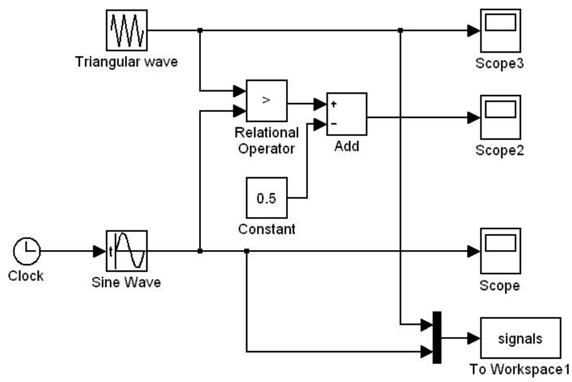

Figure IV-1, Single Phase PWM Model

The one phase simulation starts with generating the two input signals of the PWM control. The carrier signal is a triangular wave. Matlab Simulink holds lots of elements that are suitable for the task, or at least they seem to be. The best for the task was a repeated signal generator that can be set to form a triangular wave if we give the amplitudes at given times and it interpolates the values in-between them. The second input is the reference signal; this is a simple sinusoidal wave. For this there are also a lot of possibilities, we only need to be able to set the amplitude of the signal and the frequency. The output of the signal generators can be seen on the figure below (Fig IV-2).

After we have these signals we can have a comparator that compares the two signals and generates the actual control signal for the PWM.

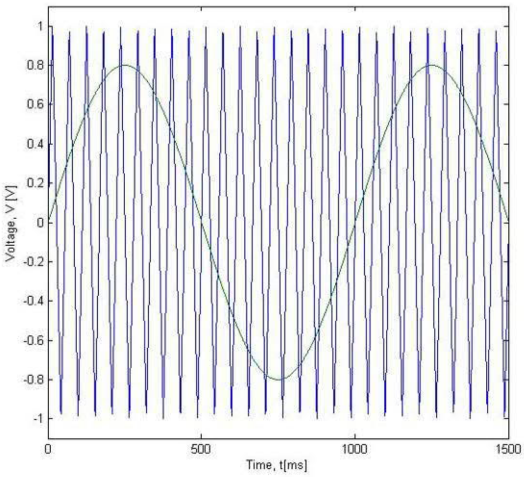

Figure IV-2, Input Signals

This control signal can be taken as the signal that we work with because the actual signal we would produce only differs in amplitude from this one. According to the theory the amplitude is dependent on the amplitude ratio and the DC supply voltage of the converter. To realize this difference in amplitude we can introduce a proportional element in the sequence thereby receiving the actual output signal. After setting the actual values of the control signals with the appropriate ratios (which are the frequency ratio and the amplitude ratio) and setting the proportional element to the given input voltage level (which represents the voltage of the input) we can start the simulation and check if the results are correct. The output of the system as a result of the comparison can be seen on the next figure (Fig. IV-3).

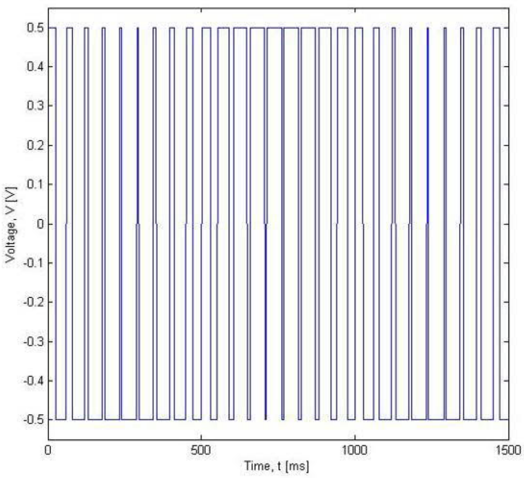

Figure IV-3, Output Signal

An additional element we can introduce is an FFT module in the simulation with which we can check the output signal in the frequency domain. (Due to the lack of experience in this program I could only introduce a short program to do the FFT, the script will be included in the paper).

The three phase simulation is not much more complicated then the one phase simulation. We only need to have three reference signals, one for each phase and still one carrier for the comparison. The configuration of this system can be seen on the next figure (Fig. IV-4).

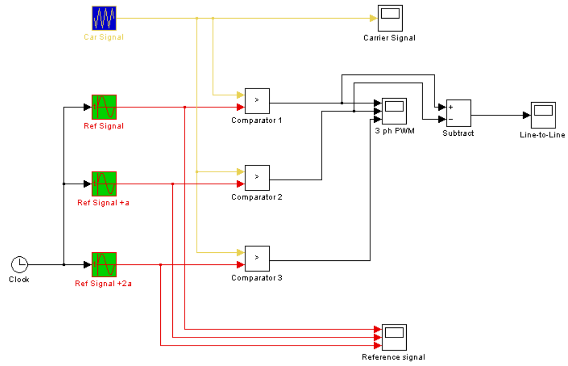

Figure IV-4, Three-phase PWM Model

The blue block is the triangular wave generator and the green blocks represent the three phases of the input. The three control signals are compared to the same triangular wave signal. The input signals and the result can be monitored on the three scopes in the model. There is one more additional part in the system where the line-to-line voltage is established from two phase voltages. This result can be then monitored on a scope or can be output to workspace for further use for other operations. The input signals of the system can be seen on Fig. IV-5.

Having the three line voltages we can take a look at the output of the comparison or make further operations on the signals. One possibility is to form the space vector of the three phase system. This can be done by simple addition, subtraction and multiplication. The definition of the space vector is:

$$\bar{X}(t) = \frac{2}{3}\left[X_R(t) + \bar{a}X_S(t) + \bar{a}^2 X_T(t) \right] \quad (4\text{-}1)$$

Where,

$$\bar{a} = e^{j\frac{2\pi}{3}} = -\frac{1}{2} + j\frac{\sqrt{3}}{2} \quad (4\text{-}2)$$

And $X_R(t), X_S(t), X_T(t)$ are the instantaneous phase values of the three-phase system.[8]
After having the space vector we can plot it to see if the result is correct, comparing it to the hand calculated result or the results that can be found in the literature. The plot of the space vector positions can be seen on Fig IV-6. We can not see too much variation in this plot if we modify the input quantities (frequency ratio, amplitude ratio), because there are eight possible positions of which two are 0 and the other six are featured.
We can also go one step further in the operation and establish the flux from the space vector by integration. This is the final step of the built model.

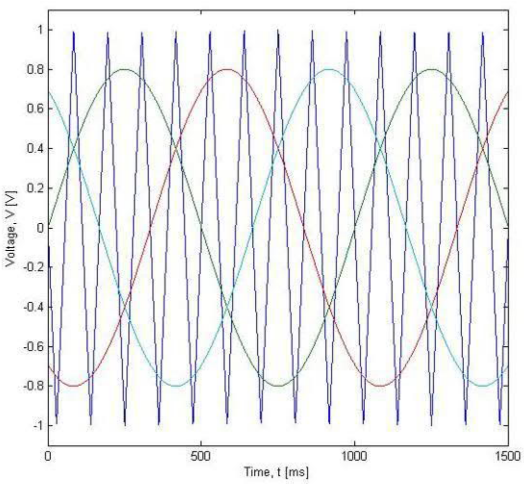

Figure IV-5, Inputs of the Three-phase PWM Inverter

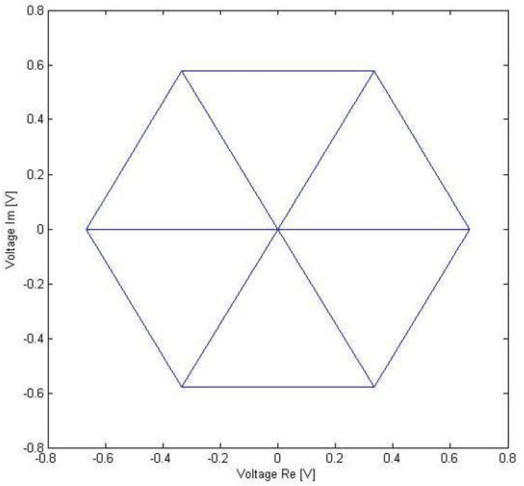

Figure IV-6, Voltage Space Vector

The information produced can be plotted to see the path of the flux, and to see the values of the space vector. Also an FFT can be made on these signals to see how the signals look in frequency domain. The important thing is to check the relations with the frequency of the modulating signal, which is also the fundamental of the output.

Evaluation of the results
Frequency domain
Flux
Flux frequency

V. PROTECTION OF THE SYSTEM

The main protection systems that are built in are the following:

- High / Low pressure on the outlet (outside tolerance)
- Over speed on the turbine
- Overheating on the generator (bearings, windings), converters heat sinks
- DC Voltage between the converters to high or low
- Over current
- Oil mist lubrication: oil, air, oil level
- Water coolant outlet pressure to low
- Sensor, PC etc malfunction

To establish the protection of the system it is important to know what are the goals of the control, what output characteristics we want to control. The purpose of the whole system is to reduce the pressure of the incoming gas to a desired lower pressure level of the normal household network. This outlet pressure needs to be kept within a tolerance independent of the quantity of the gas flowing through the system. The actual quantity flowing through varies between large barriers, due to the fluctuating needs of the users of the gas. To get the best out of the system; to reach the highest efficiency we need to make the turbine work at almost maximum capacity, this makes it most economical. Although the fluctuating flow rate and maximum capacity are a bit contradictory, they can be brought together in one solution. The turbine gets the amount of gas needed to reach a high load on it. The throttling valve built in the parallel branch gets the rest of the gas. The turbine is selected so, that the average gas flow rate would be enough to make it work close to maximum load, and at peaks in the gas need the throttling valve would be opened to let the access gas through. This makes it possible for the turbine to work at maximum load at most times, to reach a high efficiency for a shorter pay-back-time and lower investment at the beginning. The peaks that arise in the need of the gas are only for shorter periods. If we wanted to use a turbine that would be able to work during these peaks without the throttling valve, would cost much more and the efficiency of it during the average load would be much smaller, resulting in a longer pay-back-time period.

To avoid the leaking of gas the whole turning system is built in to a pressure resistant casing, with only an inlet and an outlet.

Controlling logics

In case of smaller need on the consumer side the flow is directed through the turbine. The regulation of the outlet pressure is done by the help of the adjustable turbine blade angle. In this case there is no flow on the throttling valve.

If the gas need decreases under a certain limit, the regulation of the blade angle is not enough to keep the desired outlet gas properties. In this case the emergency shut off valve is activated and we wait for the pressure on the consumer side of the system to decrease.

If the gas demand increases over a certain limit, that exceeds the capabilities of the turbine, the output pressure starts decreasing. The throttling valve opens to supply the increased need in the system with the turbine still working in parallel. If the gas demand gets smaller on the consumer side, this makes the pressure increase at the output and the throttling valve is shut out of the gas line and only the turbine works further on.

During the expansion the gas cools down more or less with respect to the load. To control the temperature of the output side, the preheater power needs to be varied to keep the temperature within the given limits.

The control of the load on the electric generator driven by the turbine needs to be solved so, that the speed of the generator is to be kept constant. By this we can guarantee that the generated energy and the used mechanical energy are in equilibrium.

If one of the protections systems is triggered (speed limit is exceeded, overload, to high temperature or output pressure limit exceeded) the control system shuts the fast acting valve. This way the flow to the turbine is blocked and automatically the parallely built in throttling valve is opened.

If any problem occurs with the turbine and it can not work as it is intended, the throttling valve automatically takes the function of it (as pressure reductor) and can supply the consumer side totally with the needed gas quantity.

VI. CONCLUSION

The simulation can not be correctly evaluated because the results seemed to be according to the literature in the beginning of the simulation with simpler tasks, but for more complicated tasks the model proved to be bad. To be more precise, for the integration of the flux signal, with integer frequency ratio, we should get a periodic signal, but the result of the simulation gave something different. The source of the fault may be the wrong selection of the input signals (they are not ideal) or there may be a problem with the synchronization of these signals.

VII. ACKNOLDGEMENTS

The author would like to thank Professor Dr. István Nagy for his help and support in the making of this project.

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CALIBRATION OF AIR FLOW METER

Figure 1, Measuring arrangement

I. PURPOSE OF MEASUREMENT

The purpose of the measurement is to register the characteristic curve of an Air Flow Meter (AFM), with the use of a through flow orifice as a reference. The air flow meter is to be measured in different configurations i.e. using different orifice diameters, different elements in the Air Flow Meter as the filter, which could cause different losses in the system. The most important part of the calibration is to point out the influences of the upstream conditions relative to the AFM. The different building blocks that compose the filter and guides have different losses. The measurement goes into detail about how the guiding cone and the filter housing effect the measured voltage compared to the measured flow rate. The assumption before the measurement results is that for a constant flow rate the AFM by itself has higher voltage then the configuration with additional elements, because of the separation zones that reduce the effective area of flow. The same effect causes for a constant output voltage on the flow meter to have smaller flow rate with just the AFM then with the whole housing attached to it.

II. GENERAL DESCRIPTION

The system consists of two main parts. The first part is the Air Flow Meter that we want to measure; the second part is the measuring section which is used for the calibration. The AFM section consists of many parts. Taking the direction of the flow as a basis the first part we come into contact is an intake cone, which is used to avoid separation zones at the intake. Then the air is lead into the filter housing. The housing holds the filter which is used to clean the air from dust and small particles. The presence of the filter introduces additional losses in the system, but if we want to simulate normal operational conditions it is necessary to take it into consideration. The filter housings upper side holds the AFM itself, to which the air can flow through another cone. After the AFM the air goes into an elbow – which is still a part of the AFM section – that leads the air to the measuring section. The measuring systems most important components are the following, the through flow orifice which is used for the actual measurement, the pump that sucks the air through the whole system and the measuring equipment. The equipment used to take the measurements are handheld membrane manometers (actually one manometer with two output channels), and digital multimeter which is used to monitor the output signal of the AFM.

It is important to point out again that the upstream conditions relative to the AFM are modified in order to see what effect the different elements have on the output signal.

III. THE AIR FLOW METER

The Air Flow Meter also has some mechanical and some electrical elements which can be investigated to work out the way the output signal is generated. According to the service catalogue of BMW the trap door like butterfly valve is connected to a resistance. The resistance is varied in the system according to the angle of the door in the valve. The door is automatically shut by a spring that has key importance in the setting of the AFM. The stiffness of the helical spring is in relation to the forces acting on the door. The force of the spring is in equilibrium with the force acting on the door due to the air flow. This means the softer the spring the bigger the change in the angle of the door, resulting in a faster changing resistance, which also changes the output voltage of the AFM. A simplified scheme of the AFM can be seen on the following figure from electrical point of view.

The wiring that can be seen on the figure are for the inputs and outputs of the AFM. These signals are the 5 V input of the AFM, the output of the flow rate 0-5 V range, the output of temperature which is for the motor control unit, and an additional cable for the CO meter which is not used in our case

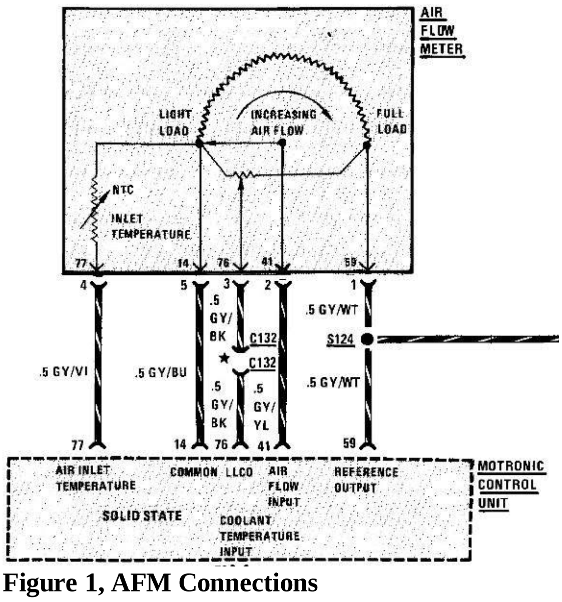

Figure 1, AFM Connections

(The car to which this AFM was built in and taken from does not use this either). There is one cable that was left out in the listing because it only serves as reference or as a common point to the other signals. The coloring of the cables is important to tell them apart. The grey/violet cable is for the temperature output, the grey/blue cable is for the common, the grey/black is for the CO meter, the grey/yellow cable is most important which is the output of the flow rate and the last cable is grey/white which is for the reference input. It is important to point out the necessity of the temperature measurement in the AFM. It is necessary to measure the temperature because the engine needs to know the mass flow rate of the air going into the combustion chamber, but without the temperature we only have information on the volumetric flow rate. The temperature of the air is used to calculate the density of the air. With the density and the volumetric flow rate the mass flow rate is easily calculated.

$$q_m = \rho \cdot q_V \qquad (1)$$

IV. MEASURING DEVICES USED

The measuring device we use in the calibration is a simple through flow orifice which works similar to a Venturi tube. Figure 2 shows a sketch of an orifice.

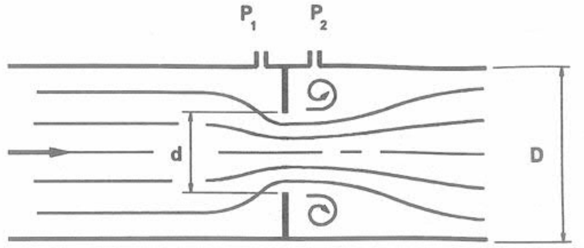

Figure 2, Trough-flow Orifice

This measuring tool is applied because it is a simple but very reliable and accurate device. The through-flow orifice plate is a contraction element placed in the flow. Because of the contraction it causes losses in the system but in our application it only influences the maximum flow rate. The basic equation used for the calculation of the flow rate, that is stated by the standard is:

$$q_V = \alpha \cdot \varepsilon \cdot \frac{d_{orifice}^2 \cdot \pi}{4} \cdot \sqrt{\frac{2 \cdot \Delta p_{orifice}}{\rho_{air}}} \qquad (2)$$

To take the viscosity of the fluid into consideration we apply a so called flow coefficient (α). This represents that the fluid is not capable of drastic deflection at the edge

of the orifice plate and separation occurs, as it can be seen on the sketch (Fig. 2). This means that the jet of fluid with the velocity of *v* does not fill the whole cross-section of the pipe. This contraction is represented by the flow coefficient. This coefficient is dependent on the ratio of diameters (pipe and orifice) and the Reynolds number of the flow.
To compensate the effect of compressibility another coefficient is applied. This is the expansion coefficient (ε). The reason for the application is: if the pressure difference measured is high enough the density of the fluid is no longer constant. The expansion coefficient depends on the measured pressure difference, the upstream pressure, the ratio of the diameters (pipe and orifice) and on the isentropic exponent of the gas.
There are strict standards considering the geometry of the orifice plate and the section it is built into. The geometry of the orifice can be seen on Figure 3.

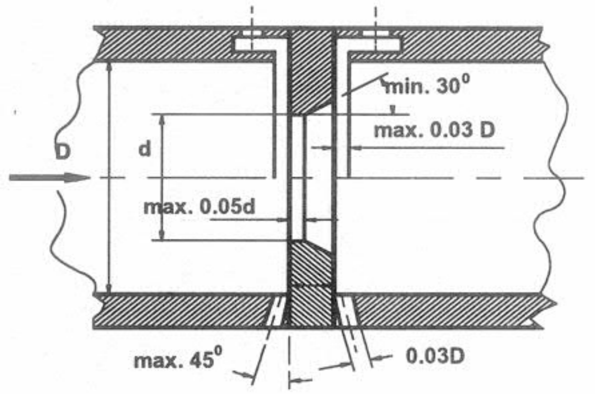

Figure 3, Orifice geometry

The orifice itself is not enough for an accurate measurement. We need to have accurate measuring devices to measure and record the exact pressure difference on the two sides of the orifice plate.
For further information on the orifice see [2F]

V. ERROR CALCULATION

The used equation for calculation:

$$q_V = \alpha \cdot \varepsilon \cdot \frac{d_{orifice}^2 \cdot \pi}{4} \cdot \sqrt{\frac{2 \cdot \Delta p_{orifice}}{\rho_{air}}} \quad (3)$$

$$\rho_{air} = \frac{p_{air}}{R \cdot T} \quad (4)$$

$$q_V = \alpha \cdot \varepsilon \cdot \frac{d_{orifice}^2 \cdot \pi}{4} \cdot \sqrt{\frac{2 \cdot \Delta p_{orifice}}{\frac{p_{air}}{R \cdot T}}} \quad (5)$$

Where:

q_V	m^3/s	volumetric flow rate
α	1	through flow coefficient
ε	1	expansion coefficient
$d_{orifice}$	m	diameter of the orifice plate hole
$\Delta p_{orifice}$	Pa	pressure difference on the two sides of the orifice plate
p_{air}	Pa	pressure of the ambient air
R	J/(kg*K)	gas constant of air
T_{air}	K	temperature of the air

Table 1, Variables

The measured variables also have accuracy. In most of the cases the error of the measurement is due to the measuring devices. This error is taken equal to the scaling of the devices. Table 2 lists the measured quantities with their accuracies.

Measured quantity	Sign	Measuring device	Accuracy
Pressure difference	Δp	Manometer	δp = 1 Pa
Ambient pressure	p_0	Barometer	δp_0 = 100 Pa
Air temperature	T	Thermometer	δT = 1 K
Orifice diameter	d		δd = 0,00005 *m*

Table 2, Accuracy

The error of the measurement is composed of the error of each measured quantity. To describe it in a general form:

$$\delta R = \sqrt{\sum_{i=1}^{n}\left(\delta X_i \cdot \frac{\partial R}{\partial X_i}\right)^2} \qquad (6)$$

For our measurement the next equation applies:

$$\delta q_V = \sqrt{\left(\delta\Delta p \cdot \frac{\partial q_V}{\partial \Delta p}\right)^2 + \left(\delta p_0 \cdot \frac{\partial q_V}{\partial p_0}\right)^2 + \left(\delta T \cdot \frac{\partial q_V}{\partial T}\right)^2 + \left(\delta d \cdot \frac{\partial q_V}{\partial d}\right)^2} \qquad (7)$$

The result of the substitution is:

$$\delta q_V = \sqrt{q_V{}^2 \cdot \left(-\frac{1}{2}\cdot\frac{\delta p_0}{p_0}\right)^2 + q_V{}^2 \cdot \left(\frac{1}{2}\cdot\frac{\delta T}{T}\right)^2 + q_V{}^2 \cdot \left(\frac{1}{2}\cdot\frac{\delta\Delta p}{\Delta p}\right)^2 + q_V{}^2 \cdot \left(2\cdot\frac{\delta d}{d}\right)^2} \qquad (8)$$

And the equation for the relative error:

$$\frac{\delta q_V}{q_V} = \sqrt{\left(-\frac{1}{2}\cdot\frac{\delta p_0}{p_0}\right)^2 + \left(\frac{1}{2}\cdot\frac{\delta T}{T}\right)^2 + \left(\frac{1}{2}\cdot\frac{\delta\Delta p}{\Delta p}\right)^2 + \left(2\cdot\frac{\delta d}{d}\right)^2} \qquad (9)$$

VI. MEASUREMENT RESULTS

The measurement resulted in a series of quantities. For one point on the calibration curve the following were registered:

- Diameter of the orifice d (once per orifice)
- Ambient temperature T (once per configuration)
- Ambient air pressure p_{air} *or* p_0 (once per configuration)
- Pressure difference on the orifice Δp
- Pressure before the orifice p_1
- Voltage of the AFM V_{AFM}

The equations used for calculation in addition to the basic equation (Eq.2).

The calculation of the flow coefficient:

$$\alpha = \frac{C}{\sqrt{1-\beta^4}} \qquad (10)$$

Where the variables C and β are:

The diameter ratio

$$\beta = \frac{d_{orifice}}{D} \qquad (11)$$

The Reynolds number characterizing the flow

$$\mathrm{Re} = \frac{v \cdot D}{\nu} \qquad (12)$$

$$C = 0,5961 + 0,0261\beta^2 - 0,216\beta^8 + +0,000521\left(\frac{10^6\beta}{\mathrm{Re}}\right)^{0,7} + \left(0,0188 + 0,0063A\right)\beta^{3,5}\left(\frac{10^6}{\mathrm{Re}}\right)^{0,3} + +0,011\left(0,75-\beta\right)\left(2,8 - \frac{D}{0,0254}\right) \qquad (13)$$

Calculation of A

$$A = \left(\frac{19000\cdot\beta}{\mathrm{Re}}\right)^{0,8} \qquad (14)$$

Calculation of the expansion coefficient:

$$\varepsilon = 1 - \left(0,41 + 0,35\cdot\beta^4\right)\cdot\frac{\Delta p}{\kappa \cdot p_1} \qquad (15)$$

For the calculation of the Re number we also need to know the viscosity of the fluid.

The dynamic viscosity is used for the calculation of the kinetic viscosity.

$$\nu = \frac{\mu}{\rho} \qquad (16)$$

The dynamic viscosity:

$$\frac{\mu}{\mu_0} = \frac{T_1 + T_S}{T + T_S}\left(\frac{T}{T_1}\right)^{\frac{3}{2}} \qquad (17)$$

The density of the gas is also calculated by the following equation:

$$\rho = \frac{p}{R \cdot T} \quad (18)$$

The constants used for the calculations are the following:

$\kappa = 1,4$

$D = 0,0594\, m$

$d_{orifice} = 0,04\, m$

$T_S = 122\, K$

$T_1 = 273,16\, K$

$\mu_0 = 1,7 \cdot 10^{-6} \frac{kg}{m \cdot s}$

As it can be seen from the equations the speed is needed to calculate the Re number, which is necessary in the calculation of *C*. But *C* is in the calculation for the flow coefficient α, which is needed for the calculation of the flow rate. This means we need a basis for the calculation. According to the experience in fluid mechanics the flow coefficient is around 0,6. We can use this as a starting point of our iteration (α'). The points of iteration are the following:

$$Measurement\ data + \alpha' \to q_V{}' \to v' \to \mathrm{Re}' \to \alpha''$$

Before the actual measurement took place we needed to make some calculations on how the measuring section element should be manufactured. This means the calculation of the estimated maximal flow rate based on the knowledge of the car the AFM was taken from. The flow rate is necessary for the selection of the blower and the diameter of the orifice plate.

The Quantitative Results of the Measurements:

V_{AFM}	q_V	V_{AFM}	q_V	V_{AFM}	q_V
3,63	39,32	3,61	39,19	3,65	39,63
3,58	37,80	3,56	37,44	3,59	37,43
3,55	36,89	3,51	35,78	3,50	34,99
3,53	36,14	3,45	34,13	3,47	34,00
3,47	34,54	3,38	31,91	3,35	30,70
3,43	32,98	3,33	30,48	3,32	29,77
3,38	31,82	3,27	29,00	3,27	28,51
3,35	30,78	3,23	27,90	3,23	27,39
3,30	29,40	3,18	26,48	3,18	26,02
3,23	27,60	3,12	25,13	3,10	24,26
3,16	25,90	3,09	24,26	3,01	22,11
3,00	22,33	3,01	22,44	2,97	21,37
2,94	21,02	2,94	21,20	2,91	20,28
2,88	19,94	2,90	20,37	2,85	19,25
2,80	18,59	2,83	19,02	2,81	18,43
2,75	17,67	2,76	17,85	2,75	17,43
2,70	16,85	2,70	16,85	2,68	16,25
2,63	15,71	2,64	15,87	2,61	15,27
2,60	15,19	2,60	15,19	2,53	14,13
2,40	12,55	2,52	14,13	2,46	13,08
2,26	11,19	2,42	12,80	2,40	12,40
2,18	10,56	2,30	11,68	2,32	11,57
2,06	9,57	2,15	10,32	2,20	10,56
1,97	8,90	1,97	8,90	2,10	9,77
1,83	7,93	1,87	8,17	2,05	9,31
1,63	6,65	1,75	7,36	1,92	8,39
1,38	5,51	1,60	6,46	1,81	7,61
1,20	4,91	1,54	6,26	1,71	7,01
0,95	4,37	1,34	5,40	1,56	6,16
0,52	3,58	1,14	4,78	1,40	5,40
		0,89	4,22	1,17	4,78
		0,63	3,75	0,81	4,07
				0,46	3,58

With the filter housing and the guide applied on the AFM, in the first two columns.
With the filer housing and no guide applied on the AFM, in the second pair of columns.
Without anything applied, just the AFM, in the third pair of columns.

The quantities are expressed in Volts for the output voltage of the AFM (V_{AFM}), and in liters per second for the flow rate (q_V).
These can also be visualized on a graph for the comparison of the different measurement conditions, as it can be seen on Fig. 4.

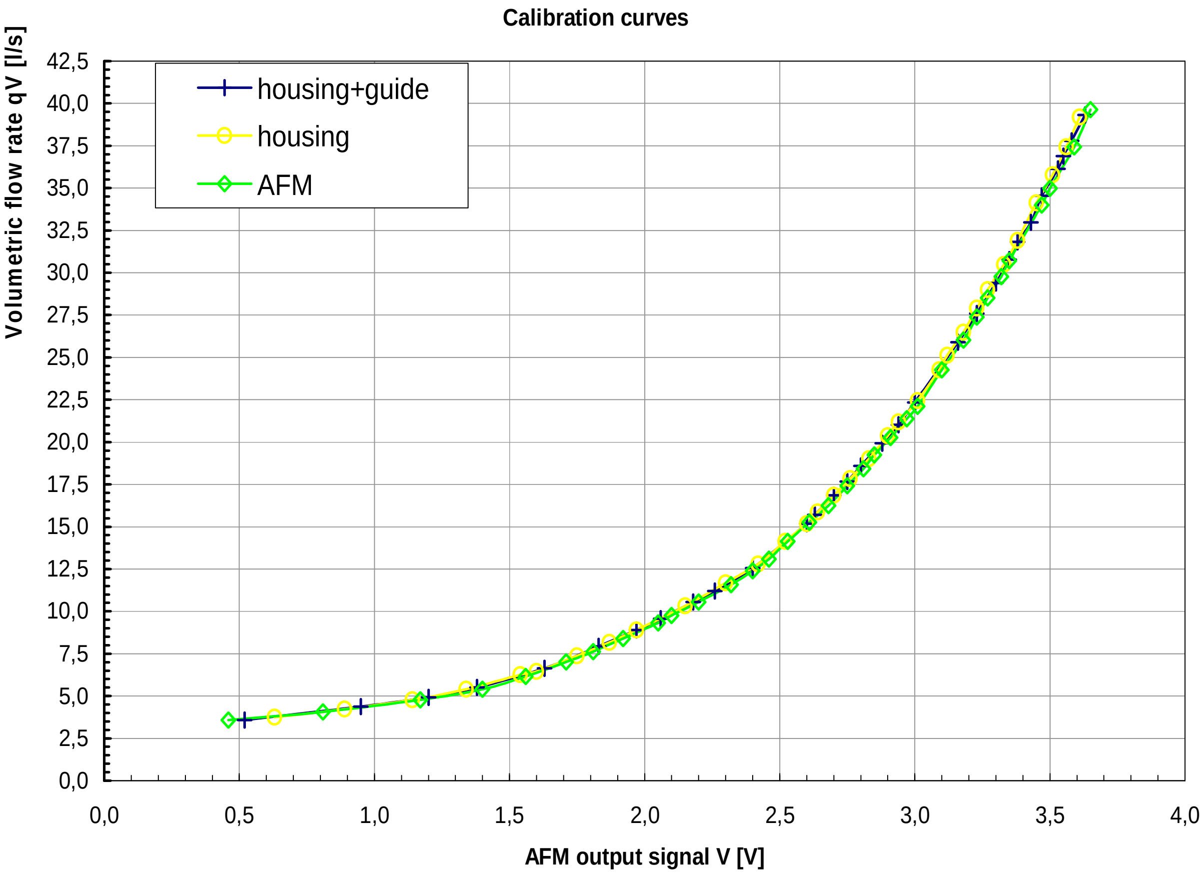

Figure 4, Calibration curves I (old)

We can see on this figure that the slope of the curve is not constant. In this example we can point out that it is important to know the flow rate at lower crank shaft speeds (that are close to the basic 850 rpm). It can be seen that the change in the voltage is much higher to the same change of flow rate at the beginning than at the end. The breakpoint, from where the curve is approximately linear, is just after the point where the basic rotation speed is. The flow rate for 850 rpm is at 12,5 l/s and the breakpoint is at about 15 l/s.
If we make an enlarged view of the graph we can see that the curves for the measurements are very close to each other but are not the same. There is a clear and noticeable difference between the blue and yellow lines and the green line. The blue and yellow line intersect each other multiple times in the calibration range, we can say that there is no significant difference between them. This can be seen on Fig. 5.
If we depict the curves with their error bands we can see that the green line is distant enough from each the other two (the error bands do not intersect or overlap; Fig.6.)
We can investigate another measurement with the same type of AFM, but this is definitely not modified. This result can be seen on Fig 7. The difference in the curves is not evident. The same color code is used to indicate the same conditions.
The same enlargements will be given for these curves as well.

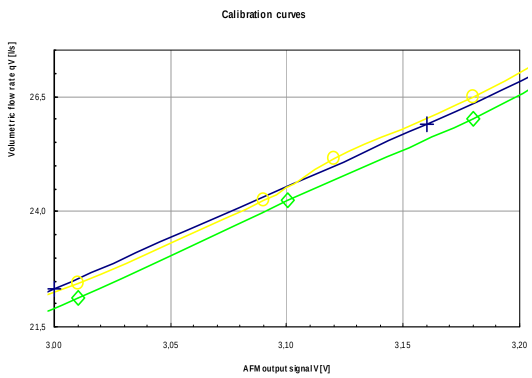

Figure 5, Enlarged view of Fig. 4.

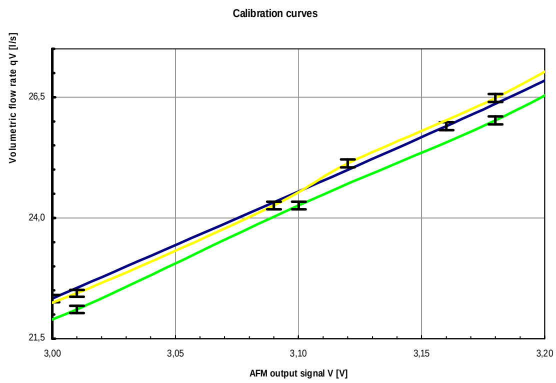

Figure 6, Enlarged view with Error bands

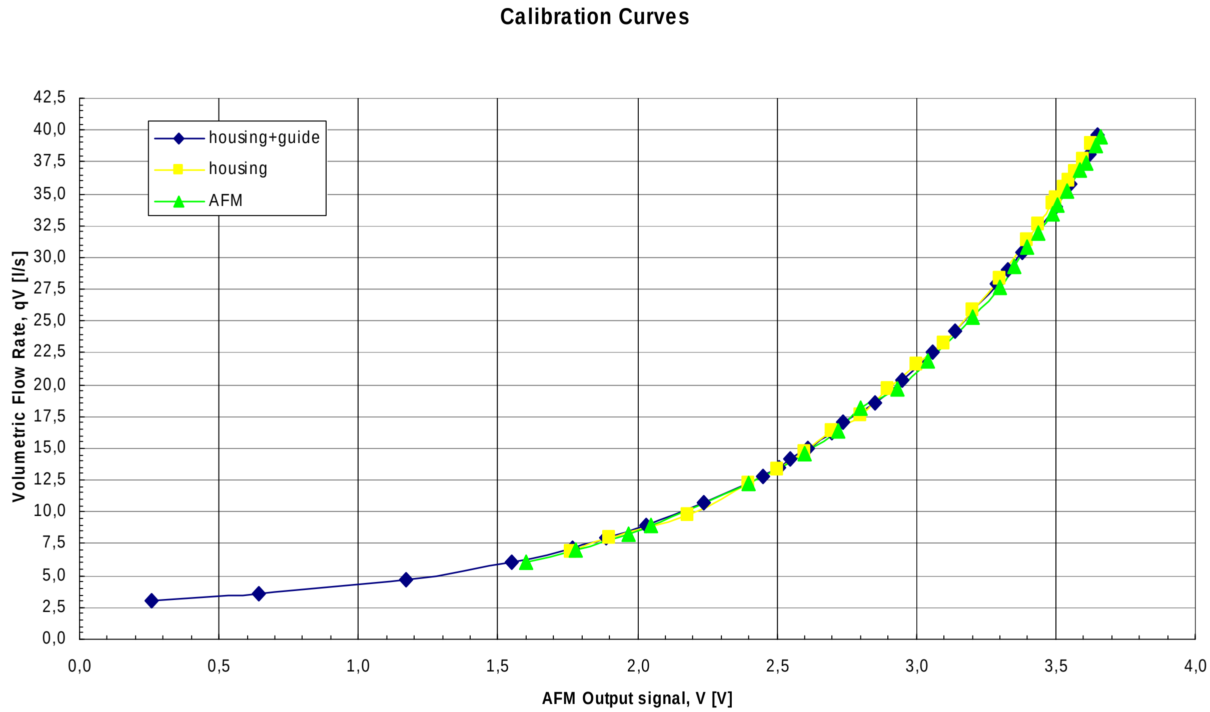

Figure7, Calibration Curves II (new)

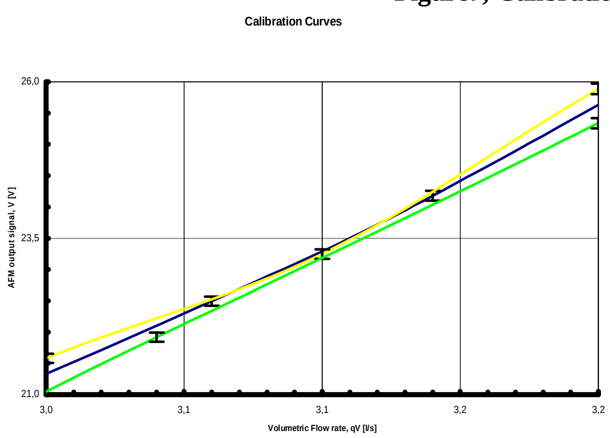

Figure 8, Enlargement with error bands

We can see that the situation is quite the same as for the previous AFM, the only difference is that the flow rate for the same voltage levels is different.

To make this clearer the next figure shows two curves from different flow meters with the same conditions. I chose the green line, which is the AFM without any additional elements.(Fig.9)

So the unmodified (or "new") AFM gives smaller voltage for the same flow rate compared to the used (or "old") AFM.

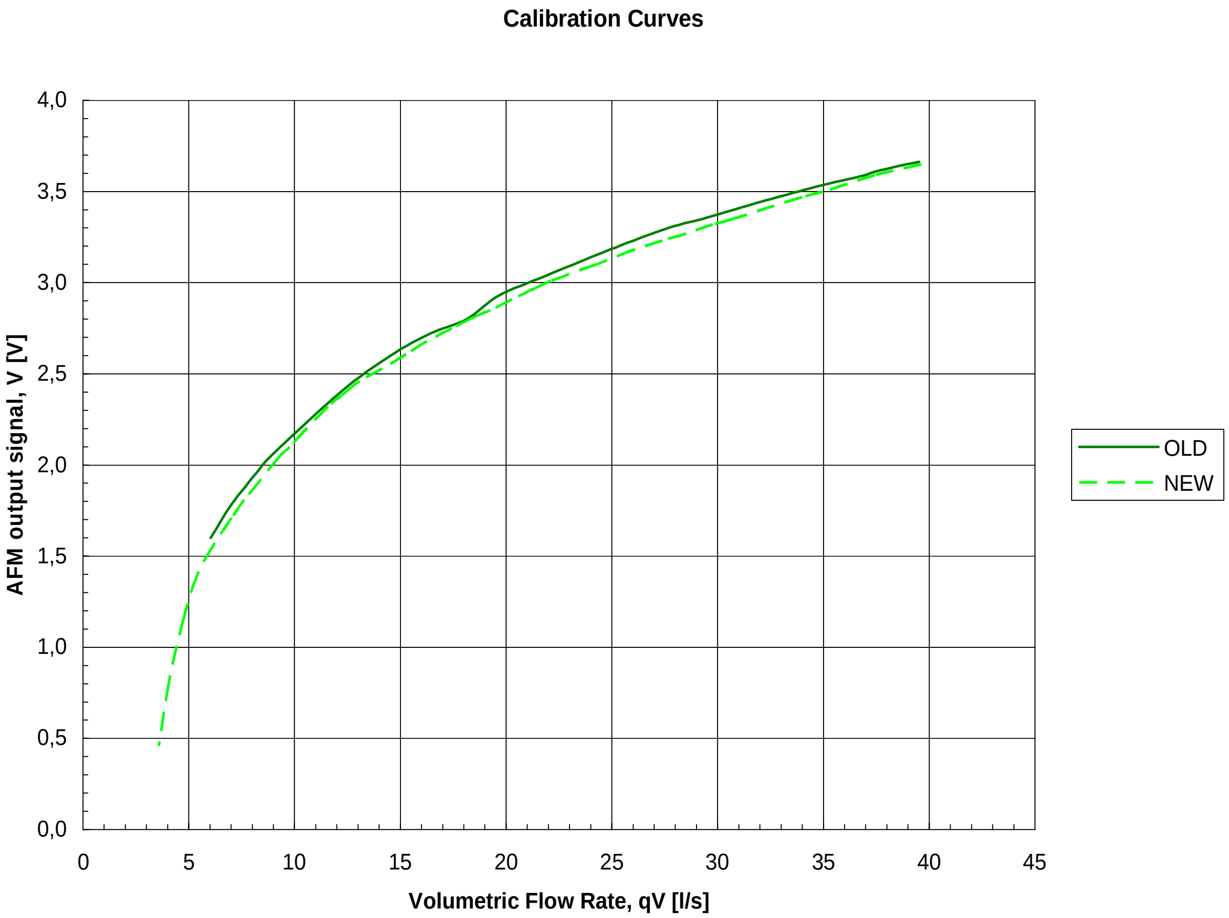

Figure 9, Compared Calibration Curves

VII. ACKNOWLEDGEMENTS

The author would like to thank Suda Jenő Miklós for his kind help and support in the making of this project.

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ECO MARKETING

Eco marketing is a new concept of marketing. The name stands for Ecological marketing this means the company or organization has goals of preserving the environment. Earlier the environmental friendliness was represented by the energy saving light bulbs and recycling, but today as the interest of people is turned to the climate change and increasing pollution. This concept of marketing tries to take advantage of this attention given to green products. One part of the concept is to let people know that the company or organization finds it important to preserve the environment, by use of recycled materials, recycling materials or by supporting the plantation of new forest (like Dell). These gestures are to improve the reputation of the company and to gain economical (sometimes even competitive) advantage over the competitors. This can be a good choice in a market that offers very similar products like the market of agricultural products. Bio fruits and vegetables are promoted to be better than others because of less (or non at all) use of chemicals and special handling (these are also controlled by government regulations). There is already standardization about how environment friendly a product is. Just to put it into numbers. There are two similar concepts the Ecological Footprint and the life cycle analysis mentioned in this study.

"Ecological footprint analysis is a measure of human demand on the Earth's ecosystems and natural resources. It compares human consumption of natural resources with planet Earth's ecological capacity to regenerate them. It is an estimate of the amount of biologically productive land and sea area needed to regenerate (if possible) the resources a human population consumes and to absorb and render harmless the corresponding waste, given prevailing technology and current understanding. Using this assessment, it is possible to estimate how many planet Earths it would take to support humanity if everybody lived a given lifestyle" [4M].

This method is more about the living standard of a group or a country. It is not too specific about a product we would want to sell, but maybe we can point out that if everybody used our product how would this number decrease.

Life Cycle Analysis has more names (Life Cycle Assessment, Ecobalance, Cradle-to-Grave analysis), but the point is always the same. It tries to evaluate the impact of the product or service on the environment. This analysis sums up all the processes in contact with the product coming to being until the disposal of it.

Most of the people would think that eco marketing is only a part of promotion and nothing is behind it. This type of marketing is mostly a philosophy of the leaders of the company. They need to be committed in order to issue these kinds of decisions, because most of the companies do much more against the environment then for it, so the realization of such behavior is an extra cost. This means they need to reorganize the company to be more environmental friendly in all aspects. Starting from selective waste collecting, through the rethinking of the assembly lines, to the raw materials used in production. For the production there are already regulations in the EU that say that most of what is produced in a company needs to be recyclable, and only a small portion can really be waste after the lifetime of the product is over. This needs a lot of attention from the engineers planning the product. And to remember this is “just” for the protection of the environment, but also a good basis for a better image that can be promoted.

It is also possible for a company to promote environmental friendly behavior by supporting other companies that are in recycling, planting forests or developing new technologies in order to have a better manufacturing possibilities or better disposal of the wastes. This is a much simpler approach, but the effect can be the same.

Another approach is to make up for the pollution at a different place like some companies do. This is called carbon offsetting. Companies offer to create carbon savings in far-off countries to compensate for emissions at home. But the effectiveness of tree planting or renewable energy projects on the other side of the world is questionable. [2M]

Eco marketing is not just for companies but also for Governments and Healthcare. The list featured shows that this is a widespread concept and as experts say it will be just bigger. (Some fields where it is used: Recycling, Waste Management, Sustainable Technologies, Energy, Alternative Technologies, Organic Products, Organic Foods, Meat Free Products, Fair-trade, Healthcare, Alternative Medicines, Wellness, Local Government). A local government can use recycled materials for its inside purposes, and can support the selective waste collecting by placing out containers, that are emptied to their expenses.

The biggest advertising agencies are predicting a wave of green marketing campaigns. Some companies say that it could become the key element of their survival. Agencies say communicating green values is fast becoming an act of "corporate hygiene" needed to retain competitiveness and standing with customers.

Some people doubt that there are commercial benefits of making environmental commitments. The acts of such matter are seen as a display of corporate social responsibility. More recently it has been argued that they can influence brand preferences of some consumers.

In some market segments it is important to have an environmental approach. The companies are racing each other in these achievements. If one company has an environmental related act, the other is bound to do the same. If the act is not done also by the competitors its absence is noticed by the consumers and they may become suspicious. This is made even harder by the fact that people are becoming more interested in the companies they are customers of. They check the web page and search to find their interest for example the environmental policy of the company. Having a good environmental policy can make the customers loyal to a brand which is the point. Loyal customers are willing to pay more for the same product.

So if we take a look at the picture before us, it is not only something a company can try out if it can increase sales or just give a better picture, but sometimes it is a must to keep the pace with the competitors. On the other hand if a company rushes into a campaign and can not hold what he stated, then he must face the consequences of the indignation of its customers [1M].

Some companies like GE produce billions of dollars each year with their green products. Tesco realizing the demands of the customers uses a new kind of labeling on its products that contains the information on the emission level for comparison, just like the nutrition facts.

The trend in the increasing market of biofuel is evident already causing arguments, because the lands used for growing biofuel crops could be used for growing grains for human consumption. [2M]

The importance of Eco marketing in our example is that this is a great possibility to promote this type of product, or the research done in the area, because this system is only in a development phase. The environmental friendliness of it is not doubtable. Depending on the size and cost of the final construction it could be used by companies and bigger houses to generate power, thereby reducing the electric bill or even generating some income.

If companies would use it they could also promote their environmental friendly acts, which is beneficial to both the producers and twice for the user.

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