Proceedings of dhe 8th IEEE Mediterrancan Conference
on Control and Automation (MED 2000)
Rio Patras, GREECE 17-19 July 2000

BAND –SAW FEED SPEED / CUTTING SPEED RATIO MEASURING AND CONTROL

STOYCHO BOYANOV*, DIMITAR PENEV**

*University of Forestry-Sofia, 1756 Sofia, Bulgaria
**Technical University of Sofia, 1756 Sofia, Bulgaria

Abstract: This paper formulates the problem of determining the cutting mode and the control mode of the band saw. The focus of this paper is the measurement of the cutting speed. It describes the structure and the operation of a device developed by the authors for direct, contact less measurement of the band-saw speed, the feed speed of the material, for estimation of the ratio of these speeds, recording and primary processing of the measurement results. A mathematical model has been created and the possibility to make a system of ratio speed control based on the measurements done by the device.

Keywords: Band saw, digital data processing, measurement of speed, ratio speed control

1. INTRODUCTION

The band-saw machines have wide application in the woodworking industry thanks to their high efficiency and little waste of material when cutting. THe deficit of wood as a raw material for the wood-working and furniture industries and the necessity of effective use require a better cutting mode as well as larger yield of the raw material, longer use of the band-saw and no mechanical damage (bending and tearing) and better quality of production.

It is known [1] that the efficient operation of the band-saw runs with the support of constant quantity of ratio feed-speed / cutting speed. The problems here are two: to find a reliable way of direct, contact less and true measurements of the band speed and, on this basis to put into effect the control system of the fixed ratio. THe speed of the band-leading wheel slightly alters during cutting (below 10 % compared to the nominal speed). Since this alteration has strong influence on the work of the machine, the maintaining of a constant value of the ratio feed-speed / cutting speed will considerably improve the working mode. When the data concerning the speeds is true (2), the solution of this problem is not difficult.

It is known that at a feed speed higher than the fixed one, which is different for different objects, the band saw loses the transversal stability and starts bending. In this case, the shape of the cut becomes curvilinear. The quality of the treated surface gets worse and the waste of wood as sawdust increase. Besides, the band saw is more likely to tear and become dangerous for the operators.

The efficiency of the band-saw machines increases with the up going feed speed. This results in a required increase of the speed of the main motion, but when the tangential power of cutting exceeds the fixed (critical) value, the band saw loses stability. The causes for waste of stability of the machine tool are various and the most frequent are: power of the band-saw stretching , width of the band, shaping of the motion, irregularly clasped or "lashed" teeth of the band-saw, oblique sharpening, heterogeneous structure of the wood; preparation of the saw during operation, mechanical fluctuations of the band-saw and a possibility of resonance, availability of band-leaders, irregular growth of the wood, knots, incomplete symmetry of the teeth, hardness of the band, etc.

2. PROBLEM STATEMENT FOR BAND SAW CONTROL

The problem of the optimization of the work of the band-saw relates to the determination of the cutting modes and their performance which assure rational combination of qualitative processing of the material, quantity of waste during cutting, electric energy consumption and security of exploitation. In this respect, there appears the necessity to solve the following problems:

- connected with the measurement of the quantities both interesting and necessary for the control of the machine, in particular, the cutting speeds of the sawing band and the feed speed of the material. The main purpose is maximum problems preciseness of measurement of the band-saw speed. This paper suggests a new contact less method for measurement of the band speed.

- problems related to the stability of the machine. It should be noted here that the band-saw proves to be extremely complicated an electromechanical system described with non-linear system of differential equations of high range. Since a considerable part of the parameters alter in the course of exploitation, or they cannot be measured, the solution of this problem becomes more complicated. To this effect, it is necessary and possible to estimate the range of stability and to guarantee it in all possible combinations of varying parameters by keeping the critical power under control.

If the condition $\frac{l^2 T}{n^2 J_a E} > 1$ is fulfilled, the critical power will be estimated by means of the formula:

$$Q_{kp} = 1.64 \frac{bt^2 \sqrt{G\sigma_t}}{l}, \qquad (1)$$

where: b - is width of the band-saw;
t - is thickness of the band-saw;
G - is module of the angle deformation of the material of the band saw;
b- is tensile stress along the band;
l -is the distance between the band-leading wheels;
T - is the power of the preliminary stretching of the band saw;
E - is module of linear deformation of the material of the band-saw;
$J_a = bt^2 / L^2$ is the inertia moment of the section of the band-saw.

The problem is complicated enough and one of the possible approaches to solve it is the interval approach [2]:

- problems related to the diagnostics of the operation of the machine.The matter is to measure some additional quantities such as the acoustic noise and the vibrations of definite, characteristic units of the machine and to measure or restore some oblique parameters e.g. powers and moments.

- problems, related to the control of the system which require use of rational control and algorithm means and based on the results obtained from the solution of the above-mentioned problems of measurement, diagnostics and guarantee of the stability. Also of great importance is the choice of a rational optimization criterion, which records the particularities of the technological process with regard to the above-mentioned considerations.

3. MEASURING OF THE RATIO FEED SPEED/ CUTTING SPEED

The precise estimation of the ratio feed speed / cutting speed (K) can be determined by the number of the markers recorded on a unit of length of the macine tool and the feeding mechanism.The method of their determination has been chosen and put into effect on the basis of innovation [3] and is described in article [4].The successive processing of the magnetic pulses is made by a device for measurement of the kinematic relation and visualization of the process. It measures:

- cutting speed V, ms^{-1}
- feed speed $U, m\min^{-1}$
- peripheral speed of the band-leading wheel $V_K m\min^{-1}$
- ratio feed speed / cutting speed (K)
- The device makes 300 records of the kinematic relation every other 0.5s during the cutting process of the wood, stores them in a memory, independent of energy and by attached software the information is transmitted to a PC computer via RS 232 driver.In the computer the information visualizes in tables and when needed it can be printed. An analysis of the work mode is made, of the speed parameters of feeding and cutting every other 0.5s and thus the qualitative parameters of the cutting process are determined. The investigations are carried out at preliminary fixed speed of feeding and cutting. This analysis gives data about the quality of the cut at various speeds of the main motion. In terms of these, a conclusion is made about the optimal feed speed $U = \frac{1}{V}$ of an adequate wooden material of definite humidity and thickness, at a definite speed of the main motion. In a system for feed control at a fixed speed of the main motion which varies depending on the abovementioned factors, the feeding follows the alteration in such a way that the preliminary estimated K remains a constant quantity. Certain standard systems [5] can be used.

The measurement device is constructed of several detached modules (see the block scheme of fig.1) and functions under the control of the specialized program safety [6].

The ***input module*** transforms the signals form the sensors and their formation into a type of signals possible to be fed to the inputs of the processing microcontroller (CMOS-levels).

The processor module is constructed on the basis of one-chip microcontroller MC 68HC11A1. In this case along with the common processing and estimating capacities of the microcontroller (CPU, RAM), it is essential to use certain specific resources of the microcontroller namely:

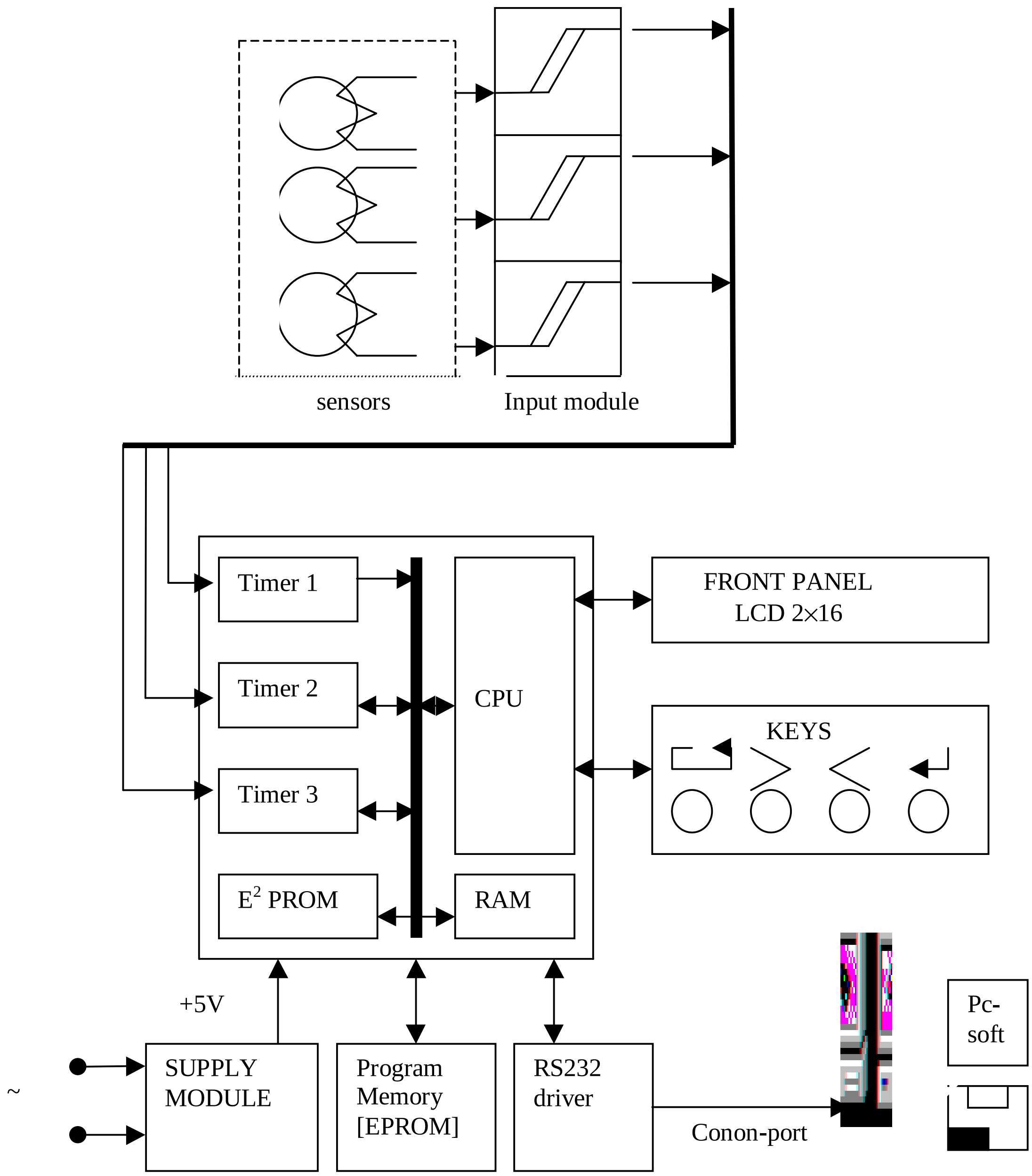
a) *Energy-independent memory* EEPROM (512B): it stores the constant quantities of the sensors, as well as the accumulated results of the measurement.

b)*Pulse accumulator*: the sensors send pulses to it about the angle speed of the band-leading wheel .

c)*Inputs and functions for measurement of time intervals* (input-capture): the signals are fed by the sensors about the feed speed and cutting speed.

d)Serial interface: performs the data exchange with the personal computer

Besides the micro controller itself, the processor module also contains memory EPROM in which the program safety of the device is recorded as well as the necessary RS 232 – driver scheme.



Indicator module contains analogue-digital liquid-crystal indicator (LCD) of the size 2 line x 16 characters which allows displaying standard symbols, figures both Cyrillic and Latin.Through this indicator and the four buttons on the front panel, the dialogue with the user and the control of the device is possible.

Feeding module provides the feeding tension for the operation of the device, the external network input is 220V AC.

The program safety of the device is made in the assembly language for the processors' family

HC11.The working cycle of the device includes several functions which can be subdivided into 4 groups:

1. ***adjustment of parameters***, including:

a) feeding sensor, number of impulses / meter;
b) cutting sensor, number of impulses / meter;
c) sensor wheel, number of impulses / revolution
d) diameter of the wheel, centimeters;

2. ***measurement mode*** – the user may choose among three types for drawing the currently measured signals:

a) feed speed and cutting speed – U, V, $m\min^{-1}$;
b) Kinematics relation – K (U/V);
c) Cutting speed and peripheral speed of the band-leading wheel – V, W, $m\min^{-1}$.

3. ***Measurement and accumulation of data*** – this function is started by a mode for measurements of the kinematics relation, where, besides the indication of the current quantity (K) every other second the values are recorded in the energy-independent memory of the device. The current version allows storage of 200 (recently measured) values and after the available memory is filled up, the record continues over the first-registered cells. Therefore, results can practically be stored for up to 200 seconds of the operation of the device. At a next start of the accumulation, it starts at the beginning of the memory i.e. the results of the preliminary measurement are lost.

4. ***feeding the accumulated data to the personal computer*** – this can be performed by the device at any time by initializing the exchange and controlling it with the personal computer. After the end of the exchange, the accumulated results remain in the memory and thus they can be reread.

Also a test version of the program of the personal computer is worked out which initializes the exchange through selected serial port, receives the data from the device and puts them out in tables.

4. BAND SAW FEED SPEED / CUTTING SPEED RATIO AUTOMATIC CONTROL

The present section discusses the model of combined work of the cutting motor and the feed motor of the band saw. The purpose of this is to clarify the possibilities for maintaining constant feed speed / cutting speed ratio utilizing the simplest and safest structure of the regulating device. The motion of the band is put into effect by an induction motor. For the purpose of modeling, the present paper suggests a mathematical model of the electromechanical part – a subject to control. Depending on the cutting strength there are two work modes:

1. Mode with missing skidding between the band-leading wheel and the band, i.e. $F_r < \mu_1 F_n$

where:

F_r – power of cutting;

μ_1 –friction ratio at rest between the band and the wheel;

$F_н$ – Power of stretch of the band. Then:

$$\frac{d\omega_1}{dt} = \frac{1}{2J + J_m}\left(M_m - M_{Fr}\right) \qquad (2)$$

Where:

ω_1 – Angle speed of the leading wheel;

J – Total (equivalent) inertia moment of the leading and led wheel;

J_m – Inertia moment of the motor, bent towards the leading wheel;

M_m – rotation moment of the motor bent towards the leading wheel;

M_{Fr} – resisting moment caused by the cutting power.

2. Cutting mode with skidding between the band and the leading wheel, i.e.:

$$F_r > \mu_2 F_n \qquad (3)$$

μ_2 –friction ratio at motion.

At the performance of the above condition there begins the mode of skidding of the band in compliance with the leading wheel when the speed of the band and the peripheral speed of the wheel are different. If we accept that the band has no elastic deformations during the transitional process, the following can be written:

$$\frac{d\omega_1}{dt} = \frac{1}{J + J_m}\left(M_m - \mu_2 M_н\right)$$
$$\frac{d\omega_2}{dt} = \frac{1}{J}\left(\mu_2 M_н - M_{Fr}\right) \qquad (4)$$

where:

ω_2 – angle speed of the led wheel;

R – radius of the leading wheel.

The mode without skidding can be resumed when

$$\omega_1 = \omega_2 \qquad and \qquad \mu_2 M_n > F_r \qquad (5)$$

The description of the process in the induction motor is based on the equations of Park (6), (7) and is of the following type:

$$\frac{d\overline{\Psi}_1}{dt} = \bar{u}_1 - R_1\bar{i}_1 - j\omega_k\overline{\Psi}_1$$
$$\frac{d\overline{\Psi}_2}{dt} = \bar{u}_2 - R_2\bar{i}_2 - j\left(\omega_k - \omega_m\right)_k\overline{\Psi}_2$$
$$M_m = pL_{12}\,\mathrm{Im}\left(\bar{i}_1 \times i_2^*\right) \qquad (6)$$

where: $\overline{\Psi}_1$ - the flux cohesion of the stator and rotor winding of the induction motor; $\overline{\Psi}2$ - tension of stator and rotor winding;

$\bar{U}_1, \bar{U}_2$ -voltage of the stator and rotor winding;

ω_k – angle speed of rotation of the coordinating system;

ω_r – angle speed of rotation of the rotor;

R_1, R_2 – active resistance of the stator and rotor winding;

L_{12} – mutual induction between the stator and rotor winding;

p – number of the poles of the machine;

$\bar{i}_1$ - stator winding current in complex shape;

i_2^* - conjugated complex of the current of the rotor.

The structural scheme of a model of the system of feed speed control of the wooden material when cutting is illustrated in fig.2.

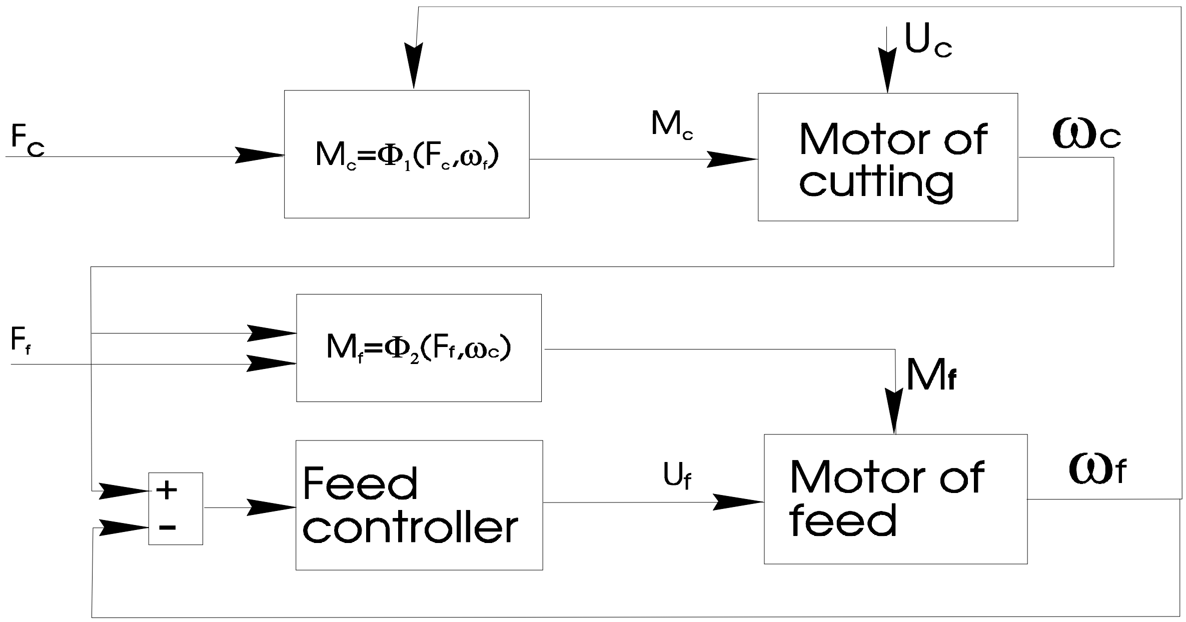


Fig.2 Structural scheme of the control system.

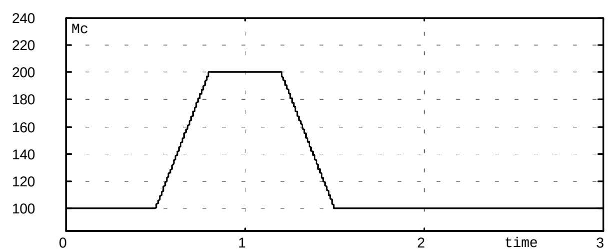


Fig. 3 Power of cutting

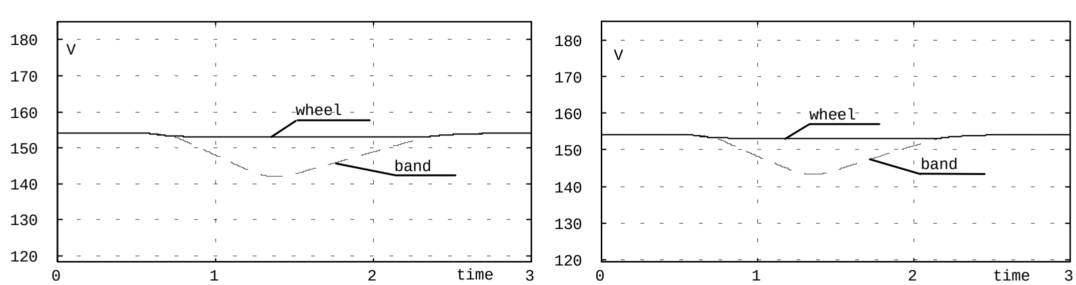


Fig.4 Speeds of the band-leading wheel and the band

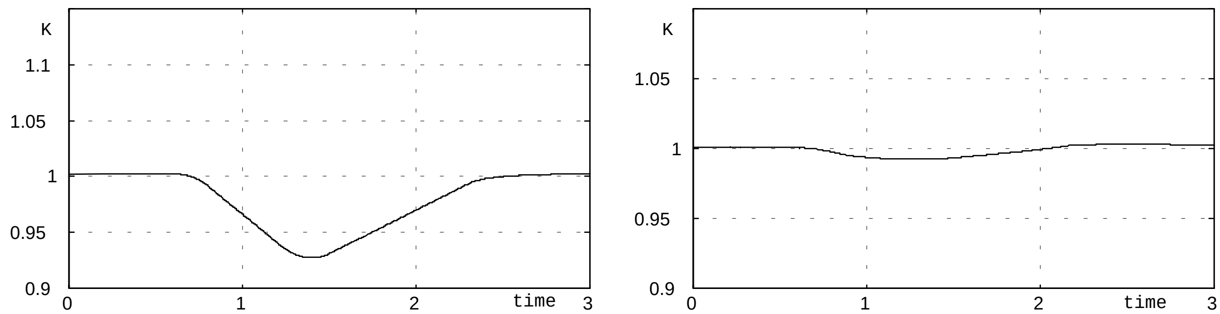


Fig.5 Feed speed / cutting speed ratio without and with control system

The regulation of the rotation frequency of the band motor is performed by PI regulator through alteration of the feeding tension of the induction motor. This regulation method has been chosen because it does not require a wide range of speed changes and the regulation is in the direction of reducing the speed (below the basic one). The investigations show that the electromagnetic processes in the motor do not influence the processes of the system, therefore the regulator of the motor tension can be least complex which will guarantee its exploitation.

The alteration of the power of cutting (and the moment related to it) is supposed to take place as shown in fig. 3.

The obtained results of the modeling are shown in fig.4 and fig. 5. It is evident that the speeds of the band and the band-leading wheel (fig.4) slightly differ in both cases. More essential is the fact that the change of the kinematics relation without control is about 8% compared to the one with control, where it is below 1% (fig.5). This makes us suggest that the application of the suggested approach and the achievement of the aims are possible and efficient.

5. CONCLUSION

An original device has been created for measurement of feed speed / cutting speed ratio, the primary data processing and their archive. The foreseen possibility for communication with personal computer allows accumulation of a larger volume of data taking into account the limited volume of the RAM of the device and the data processing. On this basis, there is a possibility to control the feed speed in view of maintaining constant value of feed speed/cutting speed ratio. On the basis of the developed mathematical model of the electromechanical process in the machine, the modeling of the system has been put into effect. The model is also based on the developed device for accumulation of data. A considerable decrease of the alteration of the feed speed/cutting speed ratio has been found at the feed speed control which will result in an increase of the productivity and in better quality of the wood working.

The independent measurement of the peripheral speed of the band-leading wheel and the linear speed of the cutting device allows efficient assessment of the presence of skidding, its size and , on this basis, the optimization of the cutting mode.

6. REFERENCES

1.Filipov G., Popov Z., Mihailov H. A Possibility to increase the stability / resistance of the band-saw during operation. DPM v.7, p. 1081.

2. Moore R.E., Methods and Applications of Interval Analysis (Philadelphia:FIAM,1979)

3.Stoycho Boyanov – Device for regulating the feed speed of the band-saw….No29237, 27.04.81, Sofia.

4. Stoycho Boyanov – Measurement of the feed speed and the cutting speed of dividing band-saw. “Wood–working and Furniture Industry” Magazine, v.2 1999,,padge 13-17, Sofia.

5. Circuit Analysis User’s Guide – Design Center v.6.2 Microsim Corporation 1995. Circuit Analysis User’s Guide, Grumi Electronik Co.1999.

6. Park R.H. –Two-reaction theory ofsynchronous machines, part I, Trans. AIEE, vol.48,p.716, 1929.

7. Park R.H. –Two-reaction theory of synchronous machines, part I, Trans. AIEE, vol. 52, p.352, 1933.