AURAL DETECTION OF LARVAE OF WHEAT

by

ROBERT EUGENE ADAMS

B. S., Kansas State College
of Agriculture and Applied Science, 1951

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Electrical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1953

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INTRODUCTION

The purpose of this thesis is to describe the research and development of the method of detecting internally infested wheat by listening to the infestation. This project is part of commercial project 51 of the Milling Department, which was undertaken by the Electrical Engineering Department.

PROBLEM

Internal infestation in wheat, by granary or rice weevil, causes insect fragments in flour. Millers are required by the Pure Food and Drug Administration to keep the fragmentation content of their flour below a certain level. This creates the problem of being able to detect this internal infestation before the wheat is milled into flour.

The granary or rice weevil is a small insect which lays eggs in the kernel of wheat. After a period of time the egg will hatch into a larva which, in turn, will start living on the kernel of wheat. The larva continues to eat and grow until most of the inside of the kernel is gone. The larva then pupates, and soon emerges as a full-grown insect. The life cycle will then repeat. Under good conditions the life cycle of the rice weevil is about 30 days. Since nearly the entire life of the rice weevil is spent inside the kernel with no visible effects on the kernel, it is impossible to detect the weevil by merely observing the grain. Thus, the need for a quick, simple, and inexpensive method of detection is readily apparent.

The problem given to the Electrical Engineering Department was to find a method for detecting the insects by some electronic system. No specifications were given as to what percentage of infestation was to be detected. A desirable system of detection would have the following characteristics: a very short time required, simple to operate, accurate, inexpensive, and as small an amount of equipment as possible.

There have been several methods developed for detecting infestation. Briefly, they are the Acid Fuchsin Stain Test, the "Cracking-Flotation" Test, Berberine Sulfate Stain Test, and X-Ray detection (3, P. 2). In the Acid Fuchsin Stain Test, the wheat is subjected to a solution of red dye. The gelatinous insect egg plug absorbs the red dye and is then visible to the eye. This test is used only to detect the egg plugs. The Berberine Sulfate Stain Test is also used to detect egg plugs, but the egg plugs are visible only under ultraviolet light. The "Cracking-Flotation" Test consists briefly of cracking the wheat just enough to release the insects existing in the grain and, after further treatment, separating the insects from the grain by flotation methods. The X-Ray technique is the process of taking X-Rays of the suspected wheat and observing the resulting films.

Considerable time was devoted to the listing of all possible methods of detection that could be imagined. Some of the more logical approaches are as follows: sound or aural detection, supersonic scanning, X-Ray scanning, infrared scanning, ultraviolet scanning, detection of body heat, detection by weight, vibration tests for difference in mass or resonant frequency, and dielectric constant tests. After much deliberation, it was decided to try the sound or aural detection method.

It was decided to use an audio amplifier with a transducer or pick-up placed in a sound-proof box. With this in mind, work was started on the amplifier.

EQUIPMENT DESIGN

Amplifier

It was thought that a rather high gain amplifier would be required for this purpose. Just how high this gain would have to be was not known. However, considering the fact that the insects in wheat could not be heard with the unaided ear and that a voltage gain of 100,000 is required for a low level microphone when used for speech, it was known the gain would have to be considerably higher than 100,000.

Colebrook (1, P. 119), an Englishman, on some work with insects in wood used an amplifier with a voltage gain of 1,000,000. Thinking that insects in wheat would quite possibly make less noise than insects in wood, a gain of 10,000,000 was decided upon as the starting point. It is not too difficult to achieve this gain in a well-built amplifier.

In his amplifier, Colebrook (1, P. 119) used alternate resistance and transformer coupling. However, it was decided to use resistance coupling only in this amplifier.

There are many good amplifier tubes both pentode and triode. However, to get the high gain necessary it is desirable to use pentodes. A 6SJ7 will have a voltage gain of about 200 when properly designed. Two 6SJ7's in tandem will then give a gain of 4×10^4. Since small sounds are to be detected, the amplifier should have a high signal to noise ratio. This can be accomplished by having a high signal or a small noise. Nothing was known about the signal, so a small noise was desirable. A small noise can be achieved by using a tube with a small equivalent noise resistance. Since triodes have a smaller equivalent noise resistance than a pentode, a triode was chosen for the input stage. A 6SF5 was used for this stage as it is a good high mu tube and was readily available. In the original circuit this stage had a voltage gain of 65. With these three tubes, there was a gain of 2,600,000, which was close to the original estimate of 10,000,000.

The next problem was to select suitable receiving equipment for the output of the amplifier. It was decided to use headphones for the output. Another tube was required to give the additional gain and to work as a low impedance stage to properly match the headphones. The impedance of the headphones was 2000 ohms. Although not measured or calculated, the gain of this output stage was thought to be about four. Now that the amplifier tube lineup had been chosen, the actual work of designing and construction was started.

There are two ways of designing audio amplifiers. The first method is to use a design procedure such as given by Reich (5, P. 159), where the values of grid swing, plate voltage, and plate resistance are all used to find the circuit constants. The second method is to use the circuit constants as given by tube manufacturers (4, P. 246) for specific tubes. This is the easiest way unless a special circuit is desired, in which case it is necessary to use the design formulas.

The circuit constants of this amplifier were chosen from charts by tube manufacturers and adapted for our use. It was found that the noise level of the amplifier was excessive and thought to be too high for our purpose. It is generally known that all tubes and resistors have an inherent noise voltage associated with them. The only solution seemed to be to use tubes with the lowest possible equivalent noise resistance (6, P. 577). If the first stage has a gain of 20 or more, then the following tubes will have very little effect upon the noise level, which leaves the input tube as the important tube.

Since the equivalent noise resistance of a triode is calculated as $\frac{2.5}{gm}$, gm being the transconductance of the tube, it is desirable to use a tube with a very high gm. The 6SF5 has a gm of 1500, and Terman (6, P. 581), in his listing of tube noise values, lists the 6AC7 operating as a triode as having a gm of 11,200, which is about the highest of any available tubes.

The input stage of the amplifier was rebuilt using a 6AC7 connected as a triode. The final circuit of the amplifier is shown on Plate I. Although, as mentioned before, the amplifier

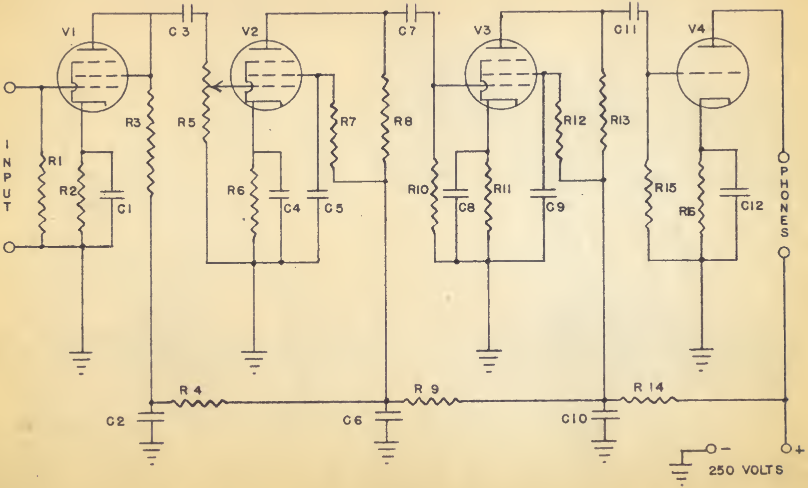
EXPLANATION OF PLATE I

High gain audio amplifier.

R1 - 5.6 MEGOHM
R2 - 150 OHMS
R3 - 4,700 OHMS
R4 - 10,000 OHMS
R5 - 0.56 MEGOHM
R6 - 1,500 OHMS
R7 - 1.2 MEGOHM
R8 - 0.25 MEGOHM
R9 - 47,000 OHMS
R10 - 0.5 MEGOHM
R11 - 1,500 OHMS
R12 - 1.2 MEGOHM
R13 - 0.25 MEGOHM
R14 - 47,000 OHMS
R15 - 1 MEGOHM
R16 - 1,000 OHMS

C1 - 4 MFD.
C2 - 8 MFD.
C3 - 0.1 MFD.
C4 - 8 MFD.
C5 - 0.05 MFD.
C6 - 0.5 MFD.
C7 - 0.01 MFD.
C8 - 8 MFD.
C9 - 0.05 MFD.
C10 - 0.5 MFD.
C11 - 0.01 MFD.
C12 - 8 MFD.
V1 - 6AC7
V2 - 6SJ7
V3 - 6SJ7
V4 - 6J5

PLATE I


V1
V2
V3
V4
C 3
C7
C11
INPUT
R1
R2
C1
R3
R5
R6
C4
C5
R7
R8
R10
C8
R11
C9
R12
R13
R15
R16
C12
PHONES
R 4
R 9
R 14
C2
C6
C10
250 VOLTS
−
+

was built to use headphones, a speaker was connected by using an output transformer since it proved to be more convenient in later work. The voltage gain of the final amplifier as measured across the speaker windings of the output transformer was 77,000. This figure represents a useful level, that is, the amplifier works very well up to this point and then the noise level becomes excessive (5, P. 196). However, when it is considered that the gain of the amplifier as actually used for detection was only between 5,000 and 6,000, the gain is sufficient. This gain was really very low, as in the design the two 6SJ7's gave a gain of 40,000. However, the output transformer had a step-down ratio of about fifty to one, which is the reason for the low gain measured. The gain, when measured in this manner, does not show the true ability of the circuit to amplify the sound energy.

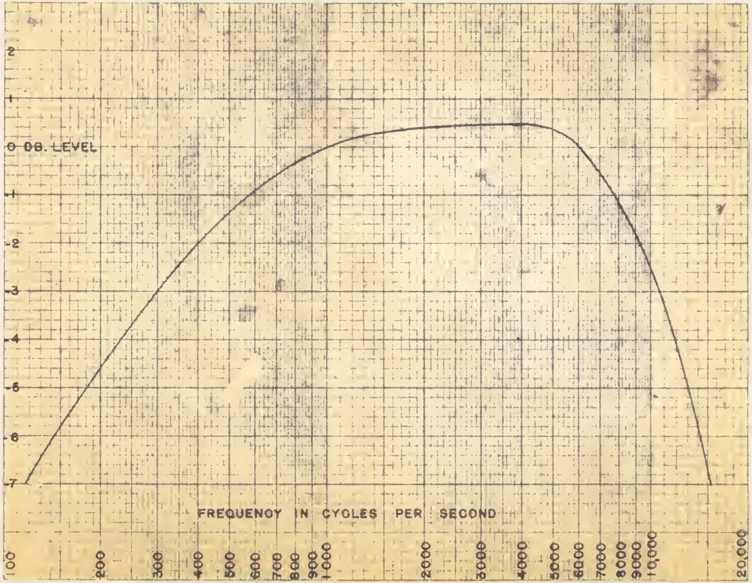
However, it must be mentioned that the gain of an amplifier is not the determining factor as to how small a signal can be detected. It is the signal to noise ratio at the first stage which limits the minimum value of signal detected (6, P. 767).

The frequency response of the amplifier was checked and thought to be satisfactory inasmuch as the type of frequency response curve necessary was unknown. The amplifier was designed to have a high low frequency cutoff to help prevent low frequency oscillations. It was thought the insects would not emit low frequency sounds because of their small size. The frequency response curve as measured across the output transformer is given on Plate II.

EXPLANATION OF PLATE II

Frequency response curve of audio amplifier.

PLATE II


2
1
0 DB. LEVEL
-1
-2
-3
-4
-5
-6
-7
FREQUENCY IN CYCLES PER SECOND
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
20,000

Soundproof Box

The design of the soundproof box turned out to be an exacting problem. Not knowing much about soundproofing and not being able to find much literature on the subject, the box was built somewhat on a trial and error basis. The first box was twelve inches square and made of a fiber wallboard material called Celotex. The box was made of one-half inch thick material, and had a recessed lid. The transducer was placed inside and connected with litz wire to give extremely flexible leads. This first box proved to be inadequate.

A second box was constructed similar to the first one and placed inside the first box. It was mounted on sponge rubber, and made small enough to give an inch of space around it. This combination worked but still left much to be desired, and considerable trouble was experienced with electrical interference. It was decided to use a copper box to shield the entire unit. The copper box was made about 16 inches square and had a tight-fitting lid. The box proved effective in eliminating the interference; however, it created another source of trouble. Inasmuch as it was constructed of 20-gauge copper, the sides were not rigid and would vibrate with any loud sound. Thus it was necessary to do further work on the box.

It was finally decided to build a concrete box of sufficient mass that any sounds would not cause the walls of the box to vibrate. The concrete box is about two feet square and two feet high and has a form-fitted lid. The complete box weighs about 450 pounds. The copper box was used as the inside form for the concrete box. For the connection to the transducer a piece of 72 ohm coaxial cable was placed in the form at the time of pouring. This box as used now is fairly effective; however, it does have a resonant frequency which lets some of the lower frequencies pass through.

The box was placed on an automobile inner tube to prevent any sound conduction through the floor to the box. This worked fine, but it was necessary to support the inner tube by wrapping it with canvas strips. A picture of the soundproof box showing the construction is on Plate III.

The Transducer

Considerable testing was done on different microphones to see which was the best for our purpose. The carbon button types have entirely too much inherent noise to be useful. Several cyrstal type microphones were tested along with a dynamic microphone. The crystal microphones were the most sensitive, and a Western Electric hearing aid microphone the best of all tested. The application for which they were used here is different from the ordinary use. The sound of the insects is not sent through air as air waves but is conducted through the wheat and microphone parts as mechanical vibrations. The hearing aid microphone has a thin dust cover which works very well for sound conduction, with the wheat being placed directly on this cover.

Although not tested, a very sensitive record player pickup

EXPLANATION OF PLATE III

Picture of the soundproof box showing construction.

PLATE III

might work very well for this purpose.

TESTING THE INPUT STAGE

Calculated Equivalent Noise Resistance

The amplifier and soundproof box were tested using a watch as a source of signal. It was not known at this time what kind of signal, if any, the rice weevils would make. The watch was used as an arbitrary standard for testing. The amplifier still had considerable background noise. So the next step was to find out how good the input stage was, as compared to a theoretical input stage. Published values of equivalent noise resistance (6, P. 581) for tubes gave 200 ohms as about the best value obtainable. We then went to work to calculate the equivalent noise resistance of the input stage. Using the equation $\text{Req.} = \frac{2.5}{gm}$ for triodes, it was necessary to find the gm of the tube. Since $gm = \frac{\mu}{r_p}$, we needed to know both μ and r_p. $A = \frac{r_1 \mu}{r_1 + r_p}$, so knowing the load resistance and measuring the amplification, r_p and μ can be found.

The procedure for doing this is to use a value of r_1 and measure the gain. Then substitute a different value of r_1, and again measure the gain. Now there are two equations and two unknowns μ and r_p. Solve the equations simultaneously for the answers.

For this stage when r_1 = 6500 ohms, A = 24, and when r_1 = 2820 ohms, A = 14. Then after solving μ = 49.3 and

r_p = 7070 ohms. Now using these values in the equation $gm = \frac{\mu}{r_p}$,

$gm = \frac{49.3}{7070}$ = 6983 micromhos or 7000 micromhos in round numbers.

So Req. = $\frac{2.5}{7000 \times 10^{-6}}$ = 357 ohms. This value of 357 ohms is good, considering the theoretical value is 200 ohms for this tube.

However, the amplifier still sounded as if the noise level were too high. This then lead to attempt to actually measure the noise figure of the amplifier (2, P. 1207).

Measured Equivalent Noise Resistance

The first method used to measure noise resistance was to short out the input of the amplifier and measure the power output. Then insert a resistance in series with the input until the output power is doubled. Then the resistance inserted will be the same as the equivalent resistance of the amplifier. Goldberg (2, P. 1211) gave this method of finding noise resistance, but did not completely qualify his statement.

This method works so long as the band width of the amplifier is less than the band width of the resistance and input capacitance combination. However, when the band width of the amplifier is the same or wider than the band width of the resistance capacitance combination, this method will not work, the reason for this being that the resistance and input capacitance forms a voltage divider network. When the resistance is raised, the band width goes down but at a faster rate. Thus, less noise voltage is applied across the input as the resistance goes up, so that an erroneous answer is given. Due to this fact, the author was never able to find a resistance which would double the output power of the amplifier.

The other method of measurement used was a noise source such as a noise diode. A noise diode is one that operates under temperature limited conditions such that the noise current, from random variations, flowing through a resistance produces a noise voltage (6, P. 579). A Sylvania 5722 was used as the noise diode with the circuit used given in Plate IV, Fig. 1. The noise diode is connected to the input of the amplifier with the filament turned off. The power output of the amplifier is read. Then the filaments are turned on and the filament current increased until the power output of the amplifier is doubled. Then the value of plate current drawn by the noise diode is read. This value of plate current is used to calculate the noise resistance. The noise voltage squared (e^2) = 4KTBR (6, P. 527) where

K = Boltzmann's constant = 1.374×10^{-23} joules per degree Kelvin.

T = absolute temperature in degrees Kelvin.

R = resistance component of impedance across which the thermal agitation is produced.

B = band width in cycles per second.

The temperature-limited diode acts as a constant current noise source of $i_d^2 = 3.18 \times 10^{-19}$ IB (2, P. 1210).

Now find the equivalent resistance using the noise diode.

EXPLANATION OF PLATE IV

Fig. 1. Circuit diagram of a noise generator.

R1 - 300 OHMS

R2 - 10 OHMS 25 WATTS

C1 - 30 MFD. 450 VOLTS

C2 - 0.1 MFD. 400 VOLTS

MA - 0-25 MILLIAMPERES

VT - 5722 NOISE DIODE

Fig. 2. Circuit for measuring output power of amplifier.

T - Output transformer

MA1 - 0-100 THERMO-MILLIAMPERES

MA2 - 0-25 THERMO-MILLIAMPERES

SW - Shorting switch for MA2

PLATE IV

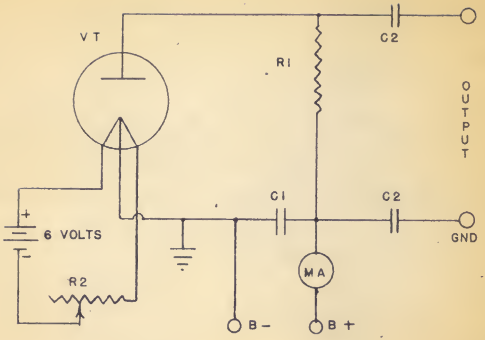


FIGURE 1

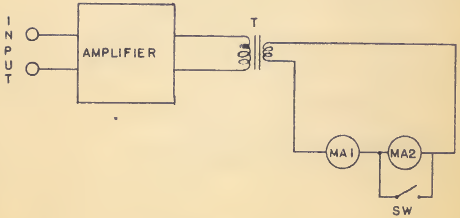


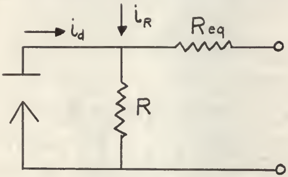
FIGURE 2

First, read the output power with the filament current zero.

$N = \frac{e_o^2}{R_m}$ where N is output power, e_o is output voltage, and R_m is meter resistance, and I_m will be meter current.

$e_o^2 = I_m^2 R_m^2$, then $N = \frac{e_o^2}{R_m} = I_m^2 R_m$.

Second, read the output power and adjust the filament current until $N^1 = 2N$, where N^1 is the new output power.



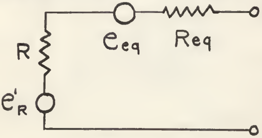
The equivalent circuit will be as shown with

$$
\begin{aligned}
N^1 &= 2N \\
&= 2\, I_m^2\, R_m \\
&= I'^2_m\, R_m
\end{aligned}
$$

The total noise current into $R = i_d^2 + i_r^2 = i^2$, and

$i^2 = 3.18 \times 10^{-19}\ I\ B + \frac{4KTB}{R}$ where $i_R^2 = \frac{4KTB}{R}$ from $e^2 = 4KTBR$.

The equivalent circuit now becomes



$$e_R'^2 = i^2R^2$$

$$e_o'^2 = e'^2A^2 = (e_R'^2 + e_{eq}^2)A^2$$

$$= I_m'^2R_m^2 = 2I_m^2R_m$$

then $e_o'^2 = 2e_o^2$ or $e_R'^2 + e_{eq}^2 = 2(e_R^2 + e_{eq}^2)$.

Now $e_{eq}^2 = e_R'^2 - 2e_R^2 = 4KTBR_{eq}$,

but $e_R'^2 = e_d^2 + e_R^2 = i_d^2R^2 + e_R^2$; therefore

$e_{eq}^2 = e_d^2 + e_R^2 - 2e_R^2 = e_d^2 - e_R^2$.

Or $4KTBReq = i_d^2R^2 - 4KTBR$ and $Req = \frac{i_d^2R^2}{4KTB} - R$.

Now, substituting for i_d^2, we have

$$Req = \frac{3.18 \times 10^{-19}\ IR^2}{4KT} - R \text{ ohms.}$$

Some trouble was encountered when using the noise diode, and the only meter sensitive enough to read the small values of output power was burned out.

While the meter was in the repair shop, further work was done using a thermistor to measure the output power. Trouble was again encountered using the noise diode. The only satisfactory thermistor available had a maximum power rating of 3.5 milliwatts. When using such a small output, any pulse type tube noise would be reflected in the output power. Two different circuits using the thermistor were tried, but neither eliminated the erratic output. Plate V shows both circuits, with Fig. 2

EXPLANATION OF PLATE V

Fig. 1. Alternate circuit for output power measurement using a thermistor.

R - 10 OHMS
C - 2000 MFD. 15 volts
T - output transformer
TH - thermistor Western Electric D167882

Fig. 2. Alternate method of using thermistor for output power measurement. This circuit keeps the resistance of thermistor constant.

R - 20,000 OHMS
C - 2,000 MFD. 15 volts
T1 - output transformer
T2 - stepup transformer
TH - thermistor Western Electric D167882
MA - 0-10 milliamperes
BATTERY - 45 volts or higher

PLATE V

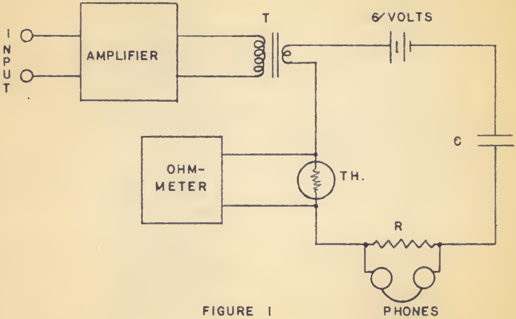


FIGURE 1

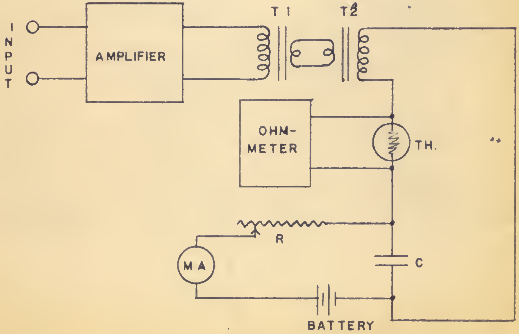


FIGURE 2

showing the circuit which allows the current to remain constant in the thermistor. Time did not permit getting a different thermistor of a higher vattage rating. However, it was found later that the noise level was sufficiently low to allow the detection of the larvae. No further efforts were made to measure the equivalent noise resistance.

DETECTION OF INFESTATION

It was quite gratifying, after many weeks of work, to be able to actually hear the weevil in the wheat. Using the loud speaker on the amplifier, the noise could be made loud enough to drive one from the room. Some time was spent just listening to the insects and trying to identify the sounds. One grain of wheat with a larva in it was placed on the microphone. It was amazing to hear the distinct noises that the insect made. There would be a low frequency scraping sound, and then a series of sharp high frequency "bursts" of noise. The best analogy to the high frequency sounds would be that it sounded like someone chewing peanut brittle with his mouth open. After considerable observation of these sounds, it was decided that the low frequency scraping was the larva moving or crawling in the grain, and the high frequency sounds were the tearing and chewing of the wheat.

Frequency Range of Sounds

Some work was done with the wave analyzer to determine the frequencies present in the sounds made by the insects. The frequencies range from 8 kilocycles per second down to about 200 cycles per second. This lower figure of 200 cycles per second is not very accurate as some difficulty was encountered with some outside pickup which could not be found and eliminated. It is the author's intention to pursue this further when the time allows. However, the frequencies had two main groupings--from 500 to 2000 cycles per second, and 2000 to 4000 cycles per second. That is, the highest intensity of sound came at these frequencies.

X-Ray Detection

The x-ray detection of rice weevils is used to some extent, and is also used here for the selection of wheat with specific stages of growth of the weevil. The technique is to use very soft x-rays. This requires not over 30 kilovolts on the x-ray tube. The tube should preferably have a Beryllium window as quartz absorbs the softer x-rays. Another very important point is that the film holder should have an absolute minimum of cardboard and paper between the wheat and film. There is a great reduction in contrast as a result of absorption of the soft x-rays by the cardboard and paper. By utilizing these techniques, good x-ray pictures will result.

Plates VI and VII show some x-ray pictures of different stages of infestation, along with a photograph of one sample after emergence of the insects.

EXPLANATION OF PLATE VI

Fig. 1. X-ray picture of infestation in pupal stage.

Fig. 2. Photograph of the same sample of wheat after emergence of insects was complete.

PLATE VI

FIG. 1.

FIG. 2.

EXPLANATION OF PLATE VII

X-ray picture of infestation in larval stage.

PLATE VII

Oscilloscope Pictures

Numerous attempts had been made to take pictures of the waveforms of the sounds made by the insects. The work was done with a Fairchild Land Polaroid oscilloscope camera. Failure of this work was due to the dim trace produced by the low voltage oscilloscopes available. An attempt was made to utilize a 12,000 volt projection oscilloscope, but this was finally abandoned because of the difficulty of using the camera attachment on this oscilloscope. Finally a Tektronix 514D oscilloscope was bought for this purpose, and good pictures have resulted. Pictures of typical waveforms are given in Plate IX.

CORRELATION OF SOUND AND INFESTATION

Waveforms

When it became possible to take good pictures, the actual work of finding a correlation of the sound and number of insects began. It was thought that there would be some correlation dealing with the peaks of the waveforms and the number of insects inasmuch as, throughout the larval stage, the insects are supposed to eat continuously. The first attempts to take pictures were to let the sound trigger the oscilloscope sweep so that waveforms showing noise peaks would result. The time delay of the oscilloscope made this work fine as far as taking pictures was concerned, but it was difficult to get just a single sweep each time. There would be two or more sweeps on each exposure. Finally, after some practice and observation, suitable pictures were obtained.

It was soon decided that this method held no promise as all the pictures would have similar waveforms as to the amount of activity, since they were all triggered on a sound pulse and would have peaks in the waveform regardless of how few or how many insects were present.

The next step was to use a manually-triggered sweep and take a large number of pictures to get a random count. With this camera attachment, two exposures are obtained on each picture. Thus it was possible to get a total of ten traces on one picture, as five traces were taken on each exposure. However, the slowest sweep speed on the scope was one-tenth of a second for the entire sweep. This appeared to be entirely too fast to give a representative count of waveform peaks.

The obvious solution was a slow speed sweep. An external sweep circuit using the condenser charge and discharge principle was built. This sweep circuit had a sweep rate of about one second per ten centimeters of sweep. The circuit diagram of this circuit is given on Plate VIII, Fig. 1. An oscilloscope picture of the sweep and calibration wave is given on Plate IX, Fig. 1.

A series of pictures were taken with the one-second sweep using four groups of insects. The results were quite disappointing. The idea had been to count the peaks on the waveforms, but this proved to be impossible on some pictures where the signal was very intense.

EXPLANATION OF PLATE VIII

Fig. 1. Slow speed sweep circuit.

R1 - 0.56 MEGOHMS

R2 - 0.27 MEGOHMS

C - 8 MFD.

SW - Normally closed micro switch

Fig. 2. Diode clipper circuit.

R1 - 100,000 OHM potentiometer

R2 - 12,000 OHMS

XTAL - IN63 crystal diode

PLATE VIII

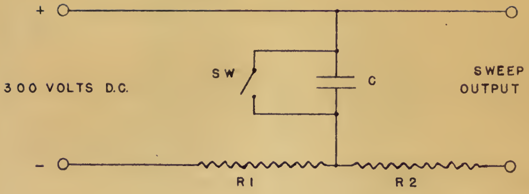


FIGURE 1

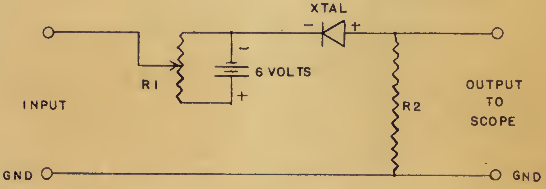


FIGURE 2

EXPLANATION OF PLATE IX

Oscilloscope pictures of waveforms

Fig. 1. Slow speed sweep of 1 second and 20 cycles per second timing wave.

Fig. 2. 1,000 microseconds per centimeter sweep showing the peaks on the waveform.

Fig. 3. 5,000 microseconds per centimeter sweep showing typical waveforms of several stages of growth.

Fig. 4. 10,000 microseconds per centimeter sweep showing typical waveforms of several stages of growth.

PLATE IX

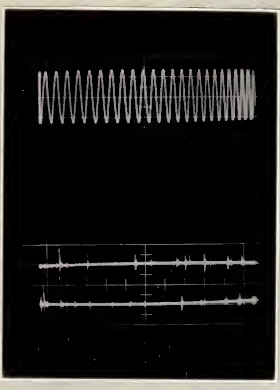


FIG. 1.

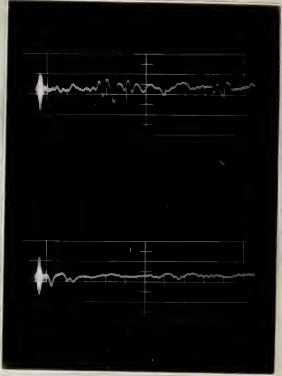


FIG. 2.

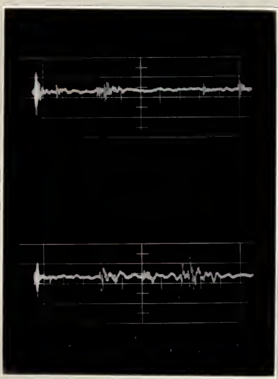


FIG. 3.

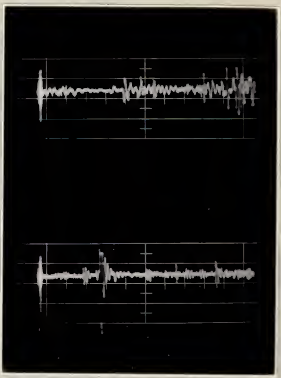


FIG. 4.

The next trial was made using a diode clipper to give only the positive part of the waveforms and to obtain a reference level to eliminate the noise showing in the waveform. This method did not work any better than the previous one as the difficulty of counting the peaks remained, so other methods were tried. The diode clipper circuit will be found on Plate VIII, Fig. 2.

Long Time Constant Vacuum Tube Voltmeter

Since the peaks of the waveforms were too numerous to count when using a long sweep, it seemed that a long time constant meter could be used to do the counting instead. A vacuum tube voltmeter could be used as the peak reading meter if the time constant were long enough. Since the time constant of the meter is built into the circuit on a vacuum tube voltmeter, an external detector was used. This was simply a crystal diode detector with a long time constant filter, and the vacuum tube voltmeter was used to measure the voltage across the capacitor. This meter then reads the peak value of the waveform of the voltage. The circuit is shown on Plate X, Fig. 1.

Tests were run using this meter with several groups of insects. At first the peak readings of the meter were used to represent the number of insects, but this did not work since the peak readings were very erratic. When a large pulse of noise came along, the meter would jump up to the value of the pulse and then slowly die out until another large pulse came

EXPLANATION OF PLATE X

Fig. 1. Circuit diagram of long time constant vacuum tube voltmeter.

T - Output transformer

R - 2.2 MEGOHM

C - 1 MFD.

XTAL - IN34 crystal

METER - Vacuum tube voltmeter

Fig. 2. Circuit diagram for connection of ballistic galvanometer.

T - Output transformer

R - Meter shunt

XTAL - IN34 crystals

METER - Ballistic galvanometer

PLATE X

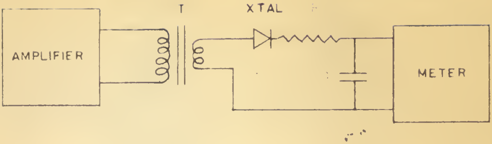


FIGURE 1

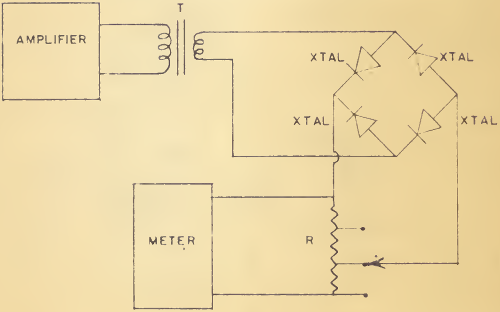


FIGURE 2

along. The peak reading of the meter was a result of the amplitude of the pulse and not representative of the number of pulses. Since one insect might make louder sounds than a younger or smaller insect, the peak readings had no meaning.

Deciding that this method would not work, another technique was tried.

EPUT Meter

Still maintaining the idea that the number of peaks of the waveform would give us the desired correlation, an electronic counter was tried. The counter was the Berkeley Events Per Unit Time meter or EPUT meter.

This instrument is automatic in its operation. It counts the incoming pulses for a time interval of one second and holds the count for a variable time interval up to 10 seconds; then it resets and counts again. The instrument has a threshold or sensitivity control so that the waveforms can be fed directly into the meter and the control adjusted to give the reference level desired.

Tests were started using four groups of four insects in each group. The procedure was to count the peaks, above a reference level, from each group; then add all groups and count the total number of peaks. To be successful the counts should also add.

The first counts were made in groups of 100, that is, the total counting time for each group of insects was 100 seconds with approximately three seconds between counts. The 100 one-second intervals were averaged to give a final figure of the number of counts per second. A new group would be placed in the soundproof box and counted about every seven minutes.

The results of these first tests held some promise of success. The tests were run over a short period of time in the hopes that the activity of the insects would remain constant over this short period. This appeared to be the wrong idea because the activity of a single insect varied greatly from one minute to the next.

More tests were run using four groups of six insects in each group. However, this time the counts were taken over a long period of time. Counts were taken every ten minutes so that a total elapsed time of 30 minutes was allowed for each group of insects. Again the counts for each group of insects were averaged into a single number. But this time it was quite successful. When the group averages were totaled, the number was the same as the average for several groups taken all at one time. Thus when one group of 6 insects had an average of 10 counts per second and a second group of 6 insects had an average of 15 counts per second, the average of the 12 insects taken at one time would be almost exactly 25 counts per second. On the entire test the maximum error was one-half per cent.

The next problem was: could this be repeated again the next day and the next. For the next two days duplicate tests were conducted using the same groups of insects. The first day the error was about seven per cent. The last day the error was close to 20 per cent. This error was contributed to the fact that the insects were in the pupal stage. When in the pupal and adult stage the insects do not seem to be predictable as to activity since they will be moving for a time and then they will be resting.

No further tests were made using the Berkeley EPUT meter. Nevertheless, it is believed that this technique could be made fairly reliable if tests were taken over a long interval of time.

Root Mean Square Meter

A suggestion had been offered sometime previously about plotting the waveforms and then averaging the entire area of the waves. It was decided to do some work on this method. Actual graphical work would be rather long and tedious, and it was decided to use a meter which would read the average or possibly the RMS value of the waveforms. This might sound similar to the previous method of using the long time constant voltmeter, but the real difference is in what the meter reads. The previous meter read the peak value of the waveform, while this meter would read the average value of the waveform.

A bridge type rectifier was used in this case with the meter being a 0 to 200 microampere meter. The idea was to increase the time constant of the meter by shunting the meter with a capacitor. However, the capacitance needed to make the time constant long was so large that the meter became a peak reading meter. The solution had to be a meter that had a high inertia. This immediately suggests that a ballistic galvanometer should be used. However, a small portable galvanometer with a period of 2.8 seconds (about 0.5 second time constant) was connected in place of the previous meter. This combination appeared to be a step in the right direction, but still a longer time constant was necessary.

Several wall-mounted galvanometers were available in a nearby room so a cable was used to carry the amplifier output to this room. A wall-mounted ballistic galvanometer with a period of 23.2 seconds was chosen. This corresponds to about a 5.5 second time constant. This is sufficiently long to give good readings. The meter does not follow every variation of the waveform, but builds up to a steadier reading. However, the meter reading does vary considerably due to the changes in activity of the insects. This variation in activity of the insects is a problem yet to be accommodated. Perhaps a solution would be a still longer time constant.

CONCLUSION

Although the problem has not been completed and will continue for sometime, the system as it now stands does have its applications. Aural detection can be used to check the effectiveness of the fumigation of the wheat shortly after it has been fumigated. This is expected to be an improvement over the method now used of waiting 30 days for any insects to emerge.

There are two methods which might prove of value in the correlation problem, and the author suggests that further research on these would be valuable and quite possibly successful. They are the RMS meter method and a frequency analysis technique.

It is the author's opinion that the clue to success of the RMS or average reading meter method is not necessarily the electrical circuit but the stage of growth of the insect itself. Possibly during a certain period of the life cycle of the insects a correlation of sound and numbers is possible. This correlation might also be true using a completely random mixture of insects.

A frequency analysis of the waveform might show a certain frequency or frequencies that would indicate a possible correlation of sound and number of insects.

The aural detection technique is also proving of interest to the entomologists who plan to use it to help determine the feeding habits of the rice weevil.

EXPLANATION OF PLATE XI

Picture of audio amplifier and associated equipment

PLATE XI

ACKNOWLEDGMENTS

The author wishes to thank Prof. J. E. Wolfe, Electrical Engineering Department, whose assistance made this manuscript possible.

To Dr. Max Milner, Milling Department, and Prof. Joe E. Ward, Jr., Electrical Engineering Department, the author is indebted for the many helpful suggestions given during the course of this work.

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AURAL DETECTION OF LARVAE OF WHEAT

by

ROBERT EUGENE ADAMS

B. S., Kansas State College
of Agriculture and Applied Science, 1951

AN ABSTRACT OF
A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Electrical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1953

AURAL DETECTION OF LARVAE OF WHEAT

This project was started at the request of the Milling Department in response to their desire for an electronic method of detecting infestation in wheat.

After studying all the methods thought possible, the idea of listening for chewing sounds seemed most logical and promising. Work was started on the equipment necessary for using this technique.

The amplifier consisted of a four-tube high gain audio amplifier which utilized a low noise triode input stage. A laboratory power supply was used along with batteries for the filaments.

The transducer or pickup was a crystal type of microphone originally used in a hearing aid.

In order to utilize the high gain of the amplifier, a soundproof box was necessary. The box consisted of four separate boxes, one inside the other. The inner box is about eight inches square and constructed of one-half inch of "Celotex" wallboard. This box sits on sponge rubber inside the second box, which is 12 inches square and constructed the same as the inner box. This box, in turn, rests on sponge rubber inside a sheet copper box 16 inches square. This copper box then forms the inside walls of the concrete box which is about 24 inches square and weighs about 450 pounds. The pickup is placed inside the inner box and rests on sponge rubber.

The actual procedure of listening for infestation is quite simple. The sample of wheat is placed on the microphone, and the soundproof box is closed. The amplifier is turned on and, if there are any insects present, they will be heard in the loud speaker.

Since the actual problem was to detect and then specify the number of insects or the percentage of infestation, the project was only partly completed. The remaining work was done on trying to find a successful method of correlation of sound and number of insects.

Three general methods of correlation were tried, with several modifications of each general method. They were: taking pictures of the waveforms and analyzing them, using meters to measure the peak, minimum, and average value of the waveforms, and using a Berkeley EPUT meter to count the peaks of the waveform.

The only method which showed promise was the use of the Berkeley EPUT meter to count the peaks of the waveform. It is fairly certain that this method will work when used over a long-time interval on the sample of wheat. However, good results were not obtained when used over a short-time interval.

Although a method of correlation was not developed, the internal infestation of wheat can be detected.

The technique of detecting infestation is thought to be useful in determining the effectiveness of fumigants on stored grain.

However, this method is not limited to detection of the rice weevil. The entomologists are interested in using aural detection to study the feeding habits of the rice weevil and other insects which infest grain.

It is hoped further work will bring to light a good reliable method of correlation of sound and insects.