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Final Report

AN INVESTIGATION OF POSSIBLE IMPROVEMENTS
IN AUTOMOBILE CLOCKS

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ABSTRACT

An investigation has been made of various means of improving the reliability of automobile clocks. After a study of various possible methods, two ways appear to be the most promising. One is to eliminate the electrical contacts by the substitution of a transistor in a feed-back system for energizing the balance wheel-hairspring combination. The other is to use a stabilized transistor oscillator to operate a synchronous motor driving the clock gear-train.

Experimental models of both types have been constructed and operated successfully. However, a considerable amount of work still has to be done on the problem of stabilizing their performance with respect to changes in temperature and battery supply voltage before a clock acceptable to the automotive industry can be produced.

AN INVESTIGATION OF POSSIBLE IMPROVEMENTS IN AUTOMOBILE CLOCKS

I. Introduction

Clocks for automobiles that are operated from the car battery have generally been a source of customer dissatisfaction because of their failure within a fraction of the usual lifetime of the car. These failures are either in the electrical make-and-break contacts used for supplying energy periodically to the clock, or they may be due to excessive wear, or to the extreme conditions of dust, dirt, and temperature found in automobiles.

The object of the current program has been to consider ways and means of overcoming the sources of trouble in automobile clocks mentioned above by the development of a novel and patentable device. This would have to be done within competitive limits of cost, and in conformance with the specifications of the automobile manufacturers.

As yet only a start has been made on the program. This has consisted (1) of investigating various electrical means of controlling the time and (2) of using the electrical energy to drive small synchronous clock motors which were obtained commercially or built in the laboratory. As yet only a small amount of effort has been put into the reduction of the effect of temperature on the accuracy of the clock, although this is one of the major problems with the type of timing

system that has been given the most attention, namely a low frequency transistor oscillator.

The time base of a clock may be either mechanical or electrical. In all present automobile clocks it is mechanical. The speed of the clock is determined by the elasticity of the hair spring on the balance wheel, and the moment of inertia of the balance wheel. In clocks that operate by plugging into a 110V-60 cycle per second wall outlet, the time base is determined electrically. A synchronous motor is driven at a constant speed determined by the power line frequency.

Theoretically, there are many other mechanisms that might be incorporated in a time base for a clock. Examples of these might be: (1) the rate of emission of particles from radioactive material, (2) rate of heat flow in a solid, or (3) the utilization of combinations of mechanical parameters other than a spring and a mass, namely, a mechanical resistance (viscous fluid) and a mass, a resistance and spring, or a combination of a mass, spring and a resistance. One of these that is simple, cheap, and insensitive to environmental effects would obviously be the most desirable, especially from a patent standpoint.

It was felt that none of the completely different systems that could be conceived offered sufficient promise to justify any work on it within the contract period. The development of an electrical time base has been concentrated on, and some effort has been expended on mechanical time bases.

II. Experimental Program

A. Mechanical Time Base Systems

There are two general types of mechanical time bases on which work was done. One used a 100 kilocycle per second piezo-electric quartz crystal which was vibrated at its resonant frequency in a conventional transistor oscillator circuit. To obtain a frequency low enough to operate a clock, it is necessary to use frequency-dividing circuits consisting of successive transistor multivibrator circuits, each operating at a lower frequency than the one driving it, but synchronized with it. A block diagram is shown in Fig. 1.

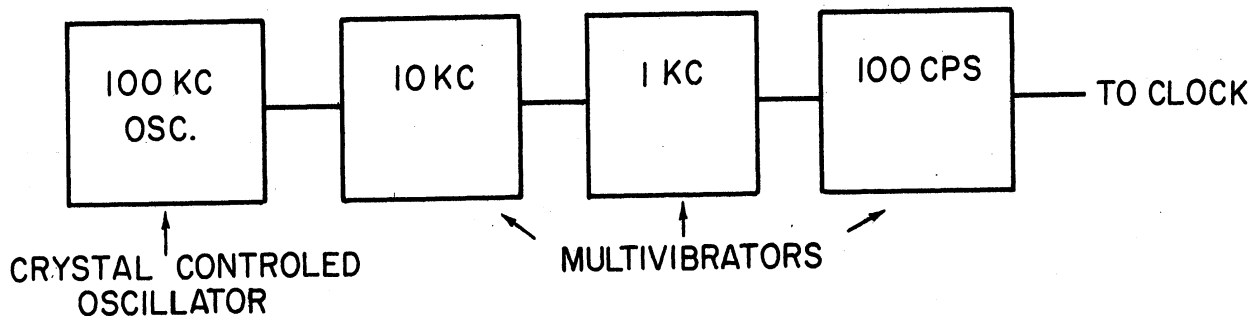


Fig. 1. Block Diagram Showing the Use of a 100 KC Quartz Crystal-Controlled Oscillator and Frequency Dividers to Drive a Clock.

The advantage of this circuit is that the dependence of the frequency of the crystal oscillator circuit on temperature and source voltage is negligible. The disadvantages are principally the large number of circuit components needed and hence the cost. A 10 to 1

reduction in frequency is the largest that is practical per stage and a more reliable figure would be 6 or 7. Hence about five stages of subdivision would be required, each having two transistors.

Another fundamentally mechanical method is to vibrate electromagnetically a mass attached to a spring. This method is described in Patent Nos. 2, 260, 847; 2, 628, 343; and 2, 443, 691. A feed-back circuit consisting of a pick-up coil and vacuum tube amplifier is provided to sustain the vibrations. In applying this method to a clock, the stiffness of the hair spring and the inertia of the balance wheel determine the frequency of vibration. Energy is supplied to the system by making the balance wheel in the form of two metal pole pieces that alternately move in and out of two separate coils as shown in Fig. 2.

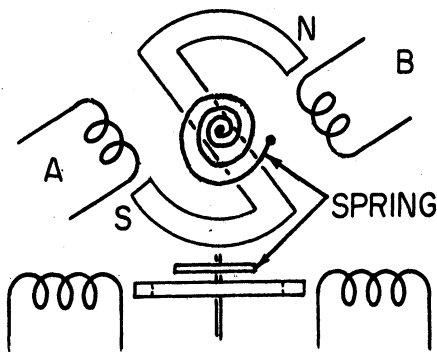


Fig. 2. This shows a magnetized balance wheel, N-S, and a hair spring mounted so that the poles N-S move alternately in and out of coils A and B.

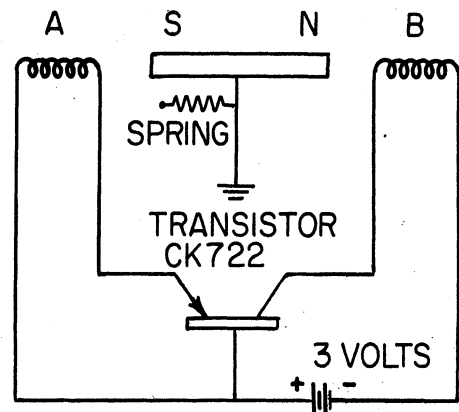


Fig. 3. A transistor hooked up to coils A and B as shown here provides feed-back from coil A to coil B to sustain the oscillations of bar magnet N-S.

These coils are connected to a junction transistor as shown schematically in Fig. 3. When the switch is first closed, there is a surge of current in coil B which attracts the armature pole N. But simultaneously pole S is pulled out of A. This will cause a surge of current in A, which will increase the flow of current in the collector circuit of the transistor. However, the poles will over-shoot beyond equilibrium and then will travel in the opposite direction into coil A and out of B respectively. The effect of this is to decrease the current in B, and thus the conditions are correct for a self-oscillatory system. Primarily the frequency of oscillation depends on the stiffness of the hair spring and the moment of inertia of the pole pieces. There will be a smaller effect on the frequency which arises from the force of the magnetic fields acting on the pole pieces. There will be a slight dependence of the vibrational frequency on temperature due to the change in the characteristics of the transistor with temperature and to a lesser extent to the change in the magnetic properties of the pole pieces with temperature. Both variations could be corrected by the use of thermistors in the transistor circuit.

The motion of the balance wheel produced in the above manner can be utilized in a conventional way to drive a clock gear train.

A system employing this principle was successfully improvised using a 10" hack saw blade for a spring, and a 1/4" rod

1-1/2 inches long for pole piece, as shown in Fig. 3. A CK722 transistor was used. The d-c resistances of the coils in the collector and base circuits were 10,000 ohms and 370 ohms, respectively.

A version of this method was constructed with the coils and pole pieces arranged in a manner similar to that shown in Fig. 3. The coils in the base and collector circuits were 2,200 turns of No. 38 wire and 2,500 turns of No. 40 wire, respectively, each being wound on a 3/8 inch diameter core. The pole pieces were permanently magnetized. With a CK722 transistor and a 4.5 volt battery, the current drain was only 0.6 milliamperes. This circuit required a 2.0 microfarad condensor across the collector coil and a 10,000 ohm resistor between the transistor base and the negative side of the battery. These two components could be eliminated by more suitable pole and coil design, however.

A modification of this system is possible in which a balance wheel shaped as shown in Fig. 4 vibrates in a gap in a magnetic circuit. It also has a hair spring attached to it.

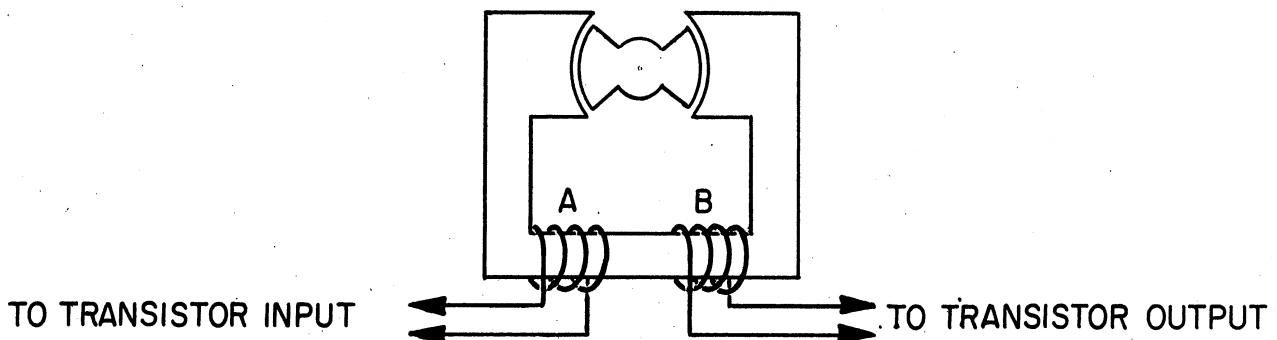


Fig. 4. An Alternate Method of Vibrating a Balance-Wheel Hair-Spring Combination Using a Transistor to Provide Feed-Back Energy.

The magnetic circuit is set up by two coils, closely coupled, one of which is connected to the input and the other to the output of a transistor in a circuit similar to that of Fig. 3. Variations in the magnetic reluctance of the gap due to the vibrations of the balance wheel set up conditions in the coupled inductance which will sustain the oscillations. The frequency of vibration is determined primarily by the moment of inertia of the balance wheel and the stiffness of the hair spring attached to it.

B. Electrical Time-Base Systems

There is a wide variety of transistor oscillators that may be used to produce a low frequency electrical signal suitable for driving a synchronous motor, which in turn may be coupled to a conventional clock mechanism. They have the uniform disadvantage that the transistor characteristics change radically with temperature (as much as 30 or 40 per cent in going from 20 deg. F to 150 deg. F). A remedy for this is to use temperature-sensitive resistances called thermistors, to compensate for changes in transistor characteristics. How this can be done will be indicated after a description is given of some of the possible circuits and motors.

The various types of oscillators that were tried in the course of the investigation generally produce either a sine wave or a square wave. Types that produce sine waves are the Hartley, Colpitts, Wien bridge, and the phase-shift oscillators. These are shown in

Figs. 5, 6, 7, and 8. Representative data on a Colpitts oscillator are shown in Table I for the circuit constants of Fig. 6. It can be

TABLE I

Dependence of the Frequency and Output Voltage
of a Colpitts Oscillator on the Transistor Base Voltage

<u>Base Voltage</u>	<u>Frequency (Cps)</u>	<u>Output Voltage (Peak to Peak)</u>
0.4	189.8	0.6
0.6	188.9	1.2
0.8	188.2	1.6
1.0	187.5	2.5
1.2	186.9	2.8
1.4	186.1	3.2
1.6	185.9	3.5
1.8	185.4	3.8
2.0	184.3	4.2
2.4	183.1	4.6
2.6	182.5	5.2
2.8	182.7	5.3
3.0	186.1	5.3
		5.4

seen that even though in this circuit the principal frequency-determining elements are the inductance and condensers across it, the base voltage variations affect the frequency as well as the output voltage. Hence the need for stabilization, since the internal base resistance and therefore the base voltage will vary markedly with temperature.

Figs. 9 and 10 show typical multivibrator circuits, the first one of which utilizes a type of capacitance feed-back system and hence has an "R-C" time constant, where R is the resistance

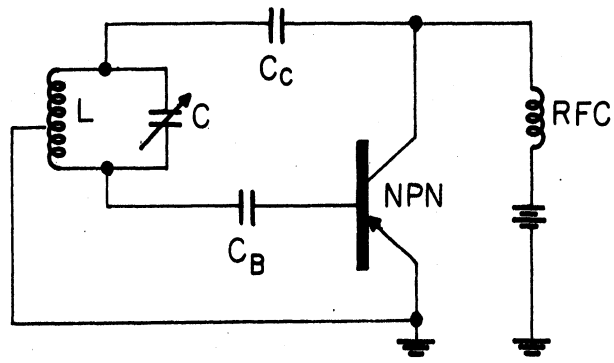


Fig. 5. Transistor Hartley Oscillator

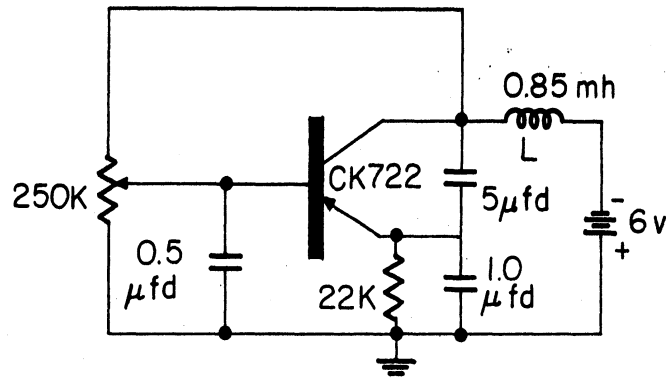


Fig. 6. Transistor Colpitts Oscillator

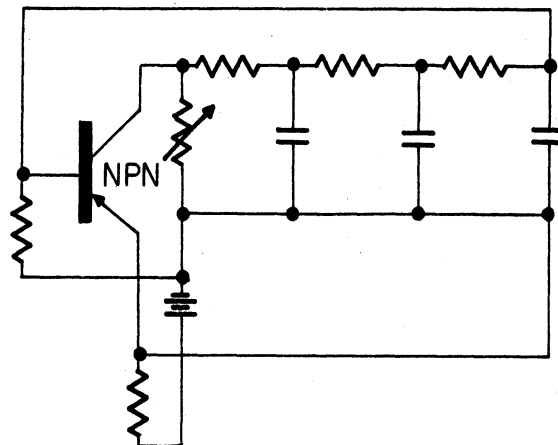


Fig. 7. Transistor Wien Bridge Oscillator

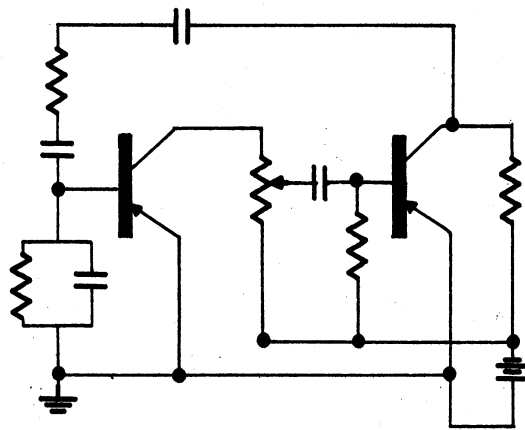


Fig. 8. Transistor Phase-Shift Oscillator

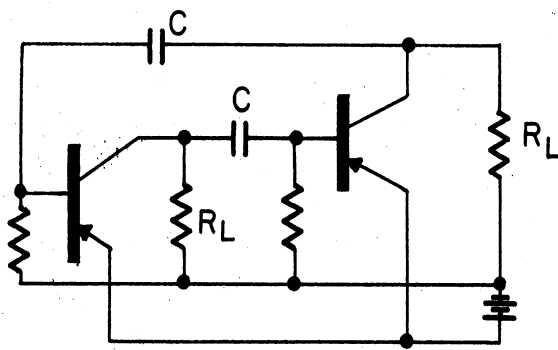


Fig. 9. Transistor R-C Multivibrator

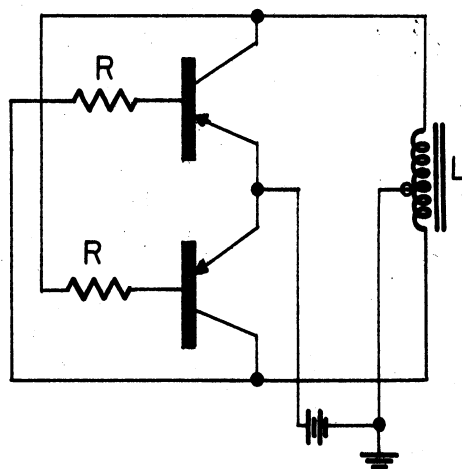


Fig. 10. Transistor R-L Multivibrator

at the base connection of the transistor and C is the coupling capacitance. Fig. 10 shows a type of inductance feed-back system. Here the time constant is approximately L/R , where L is the effective inductance between the collector connection of the transistor and the center-tap of the transformer.

Of these various types the most promising one seems to be the multivibrator, and in particular the inductance type. The advantages of this oscillator are: (1) small number of components and (2) no d-c component of current flow through the transformer and hence becomes wasted as far as clock operation goes. In the actual production model, the transformer could be eliminated and the field winding of the clock motor substituted for it, with an improvement in efficiency. In this case, the field winding would be center-tapped. The frequency of the generator would be adjusted by making one of the base resistors variable. Temperature compensation can be accomplished by the use of thermistors in series with the base resistor or connected between the base and the emitter, or by use of both arrangements. The object is to keep the voltage at the base constant as the temperature changes. If this is done, the frequency will remain constant.

A type of inductance multivibrator has been constructed using the circuit shown in Fig. 10, in which the inductance " L " is the secondary winding of a 12 volt filament transformer. The frequency

and output voltage dependence of this circuit on temperature is shown in Table II. An ordinary 2 watt clock, commercially available, was operated successfully on the 110 volt side of the transformer with a 1.0 microfarad condenser across it to bring the frequency of oscillation down to 60 cycles per second. However, this particular set-up is unsuitable for use in an automobile because of the excessive amount of power required. For example, the current drawn by the circuit in Fig. 10 is several hundred milliamperes, whereas a satisfactory automobile clock should operate on 20 milliamperes or less.

TABLE II
Variation of Frequency, Collector Current, and
Transformer Output Voltage for a Type of Inductance
Multivibrator Hooked up to a Conventional Clock

Temperature Deg. F	Frequency cps	Total Collector Current I (MA)	Output Voltage
72	104	650	123
74	104	650	123
108	103.6	650	120
110	103.6	650	122
120	104	650	118
130	105	700	112
138	106	725	110.5
143	107	775	108
151	106.4	775	108

In an effort to eliminate the transformer in the circuit described in the preceding paragraph, a simpler version was tried in which

the inductance "L" was the field coil of the clock. Although several different field coils were built, it was not possible to get the circuit to oscillate because of limitations in coil design imposed by the clock motor which was an Inghram. A problem that exists is that the inductance has to be high in order that the frequency be sufficiently low but at the same time the impedance (and hence the inductance) must be low in order to match the characteristics of the transistors. The solution lies in using a different motor design and a transistor whose characteristics are intermediate between a 2N256 and a 2N34.

The circuit shown in Fig. 11 is a modification of that in

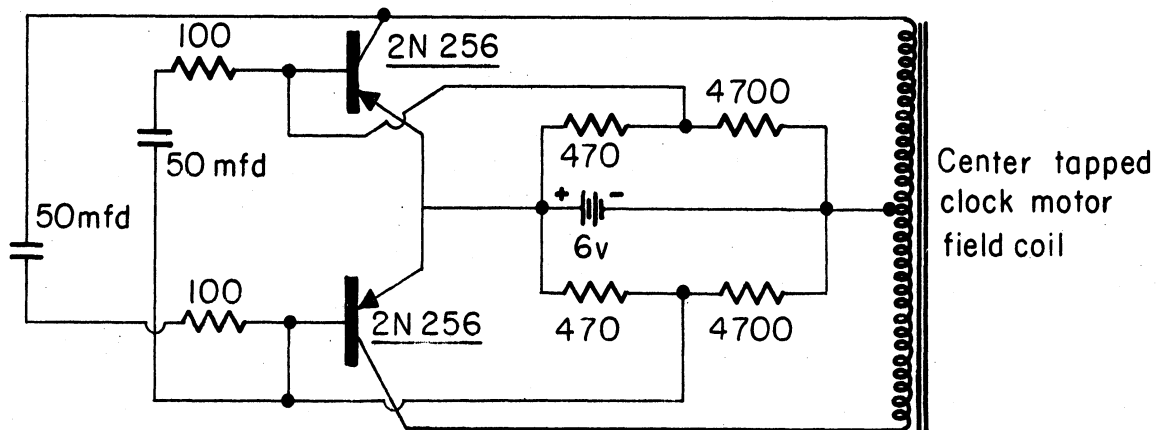


Fig. 11. Schematic Diagram of a Capacitance Multivibrator in which the Clock Coil is the Load for each Transistor.

Fig. 9 in which the load resistances R_L are replaced by the two halves of the clock field coil. This arrangement was made to drive an Inghram clock in which the original field coil had been replaced

by one wound with 1150 turns of No. 30 wire. The current drain with the bias resistors shown in Fig. 11 was 100 milliamperes. However, this current was too high for the wire size and the coil burned out after a short time. What is needed in this circuit is likewise a more efficient clock motor design that will permit operation with less current.

The capacitance type multivibrator with a resistor in one collector circuit and the motor coil (3500 ohms) in the other has also been constructed and made to operate a laboratory-built synchronous motor coupled to a Jaeger clock mechanism (See Fig. 12). CK722 transistors were used and the power consumption was only about 20 milliwatts. The disadvantage of this type compared with the inductance type multivibrator is primarily the need for extra components, that is, two extra resistors and two condensers. Both circuits still would require stabilization with respect to changes in voltage and temperature.

Synchronous Motor Design

In its simplest form, a synchronous motor needs to have only two field poles in between which the armature rotates as shown in Fig. 12. The armature itself consists merely of a bar of iron whose ends are shaped so as to provide a minimum gap between it and the pole pieces.

For a more refined motor with self-starting characteristics the shaded pole motor shown in Fig. 13 can be used.

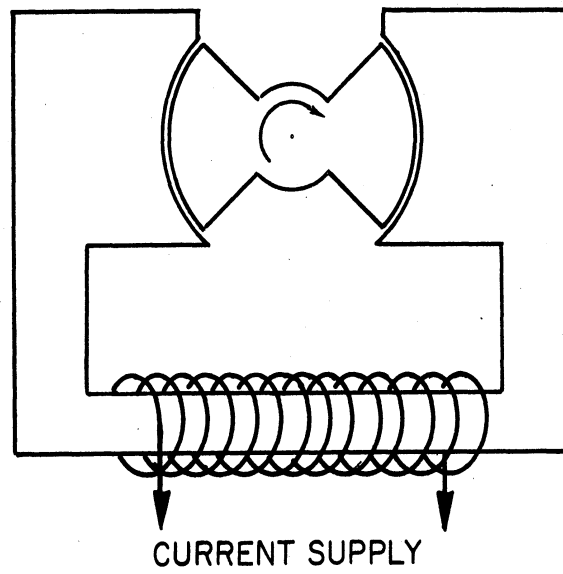


Fig. 12. A simple Synchronous Motor Design

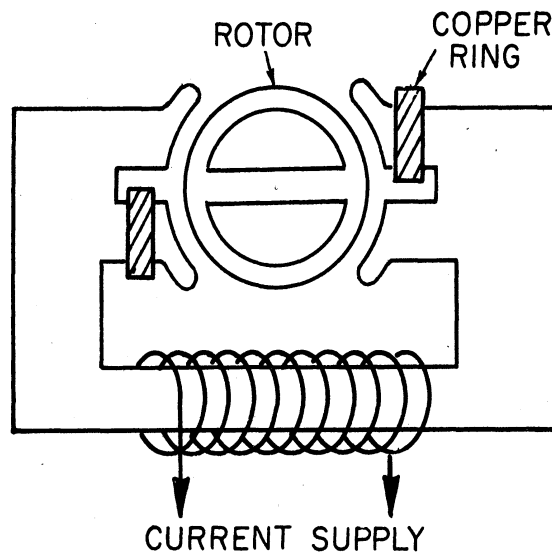


Fig. 13. Shaded Pole, Self-Starting Synchronous Motor

It will always start in the same direction if the magnetic field is made asymmetrical, so that there is a greater reaction force between the armature and field poles in one direction than in the other. The shading is done by putting a closed loop of large copper wire around one corner of each pole. The eddy currents induced in this loop set up a magnetic field of opposite direction around that part of the pole enclosed by the loop. This decreases the field there, thus making the total field asymmetrical.

It is advantageous as far as the size of the oscillator components is concerned to be able to use as high a frequency as possible up to a point where hysteresis losses become too great. At the same time, it is desirable to keep the motor speed low. This can be accomplished by using multi-pole motors. A shading effect can also be obtained with this design to make it self-starting. Fig. 14 shows

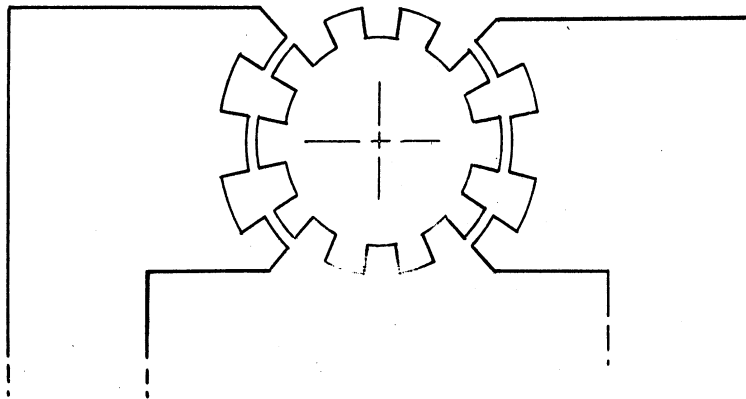


Fig. 14. Multipole Synchronous Motor
Armature and Field Poles

a way this may be done. The magnetic field rotates 180 deg. while the armature makes $1/n$ revolutions, where n is the number of poles or slots on the armature. Thus, in a simple two pole motor, the armature will make one complete revolution for a 360 deg. rotation of the magnetic field, i. e., for each cycle of the driving frequency. For a 20 pole motor, and a driving frequency of 100 cycles per second, the number of revolutions of the motor shaft per second is

$$N = \frac{2f}{n} = \frac{2(100)}{20} = 10 \text{ rev/sec.}$$

Telechron motors have two pole armatures and hence a shaft speed of 3600 rpm. Westclox (a Haydon unit) and Inghram clocks use multi-pole rotors.

Telechron, Westclox, and Inghram units have all been made to run using a Hewlett-Packard audio oscillator Model 200 AB as a source of power. The minimum power required to keep the clocks running was about 0.2 watts. They will not be self-starting until their rated power of almost 2 watts is applied.

Efficiency or total power requirements are not of major concern in the manufacture of conventional electric clocks. Hence it is to be expected that without too much difficulty a motor of lower power can be produced to operate in the range of tens of milliwatts. A simple two-pole motor using a 3500 ohm field coil was built in the course of the work and it would operate a conventional Jaeger

clock gear train with an input power of about 20 milliwatts supplied by a multivibrator circuit. It was not self-starting, however; the additional power requirement to make a clock self-starting may be three or four times that for the non-self-starting clock.

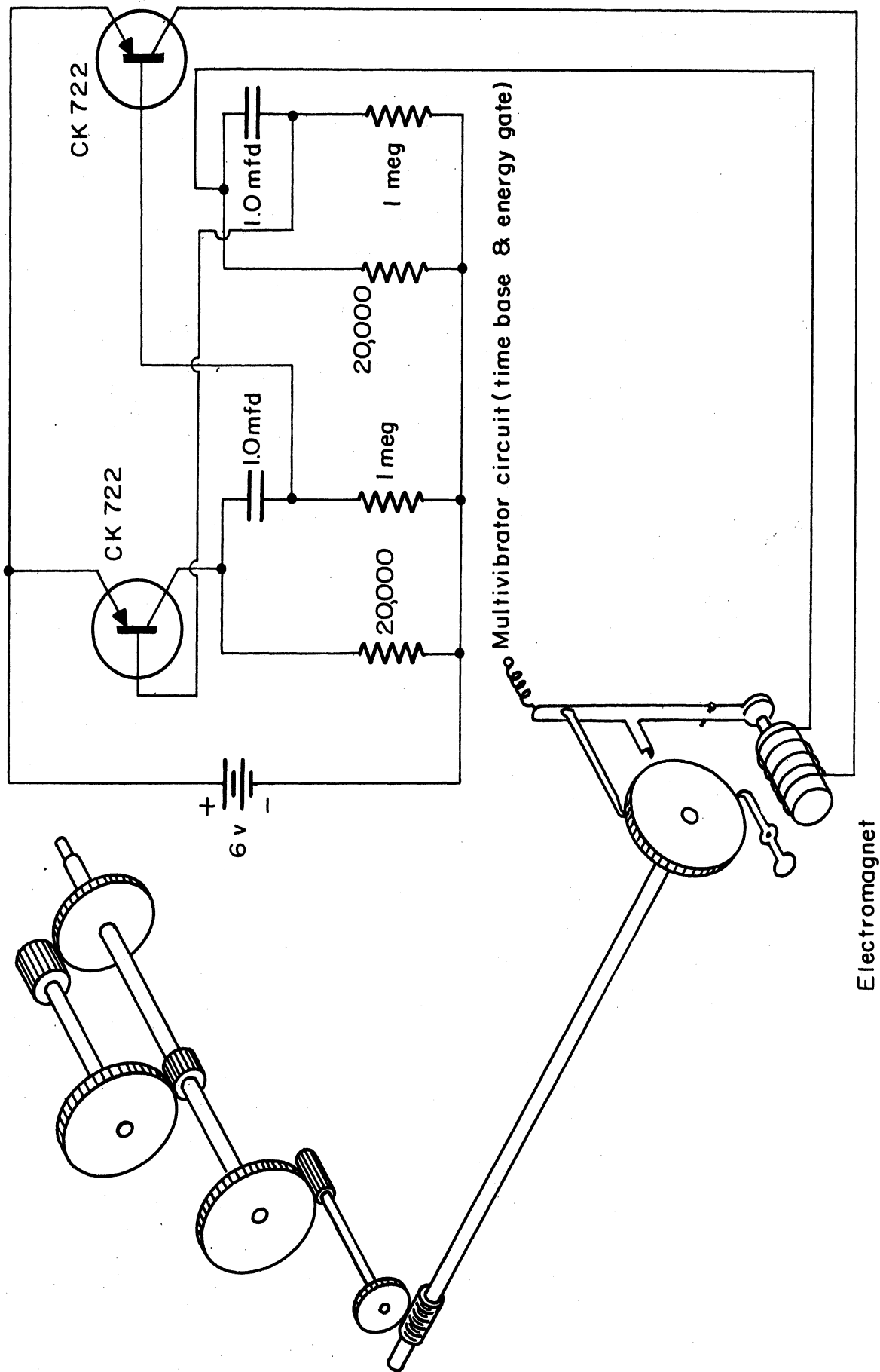
An alternative system to using a synchronous motor is shown in Fig. 15. The magnet coil which actuates the ratchet and gear train mechanism may be driven by a simple multivibrator circuit, thus providing a clock mechanism in which make-and-break electrical contacts do not exist. This system was not worked on other than to demonstrate the principle by operating a conventional type of relay, because of the greater mechanical simplicity of a synchronous motor and the probability of less wear in the latter.

Conclusions and Recommendations

As a result of the investigation of the various possible methods of driving a clock gear train from power supplied by the automobile battery, two stand out as likely to be more feasible than the others. They are:

- (1) a spring and balance wheel combination which is kept oscillating by an electrical feed-back system utilizing a transistor, and
- (2) a type of synchronous motor driven by a stabilized transistor multivibrator circuit.

Gear Train (Time Indicator)



Electromagnet

Fig. 15. The multivibrator circuit drives the electromagnet which actuates the ratchet mechanism and turns the gear train.

Both systems are capable of driving a clock with a sweep second hand. Likewise, both can incorporate a method of automatically correcting the timing system in case either needs to be reset. The first method utilizing the balance wheel and hair spring combination can probably be perfected in less time than the other, because the problems of stabilizing the transistor oscillator frequency to make it insensitive to fluctuations in frequency temperature and voltage would not have to be worked out. The first method would also be cheaper because of the fewer components. The principal disadvantage of the first one is the effect that dirt and poor lubrication may have on the accuracy of the mechanical timing system.

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