[*The following undated document was probably used by IBM instructors in training International Time Recording Company customer engineers, sales representatives and other employees in the principles, operation and maintenance of ITR master and secondary clocks and associated equipment*.]

MASTER CLOCKS

The master clock, sometimes called the "supervisory clock" is, as its name implies, the controlling element in any electric time system. Since the duty of this clock is to control the time-keeping indications of all clocks under its supervision, it must be a very high-grade instrument.

The master clock operating on what we will term a straight impulse system, as differentiated from that of an hourly supervised system, has the sole function of an "emitter" of electrical impulses at equal periodic intervals. These are transmitted over the several circuits to the various secondary clock units which are connected thereto. The secondary clock units receive these impulses and are actuated to reflect the chronological condition of the master clock. The failure of a secondary clock to respond to any of these impulses due to causes such as current interruption, line troubles, etc., will cause these secondaries to lag behind the master clock proportional to the number of impulses that are either not received or not acted upon. To correct the errors due to such causes International [IBM's ITR] provides an hourly supervised system which adds to the straight impulse system additional impulses in order to correct each secondary which may have departed from synchronism with the master clock.

In such a system the additional impulses are used whenever a secondary is behind the master clock. This use of additional impulses is accomplished through extra switches and a third wire so connected electrically that the impulses are allowed to reach any particular secondary magnet only when needed. Obviously a part of the controlling system of switches will consist of a single switch located in each secondary just ahead of the magnet.

In the design of any clock there is one definite starting point, the minute hand must make one revolution per hour. The gearing ahead or in back of the minute hand shaft may be anything within reason, depending upon the conditions. The gearing from the center shaft or minute hand shaft to the escape wheel is dependent upon the number of beats per minute of the pendulum or balance wheel. The fewer the number of beats required per minute, the less the gear reduction. The gearing from the center shaft to the source of power (weights or springs) is determined by the length of time it is desired for the clock to run with one winding. These facts account for some clocks appearing to be much more complicated than others. In our spring-driven master clocks there is no gearing from the center shaft to the source of power as the main spring is placed on the center shaft, but with our weight-driven master clocks, which are required to run a maximum of 8 days, there must necessarily be quite a train of gears in order to reduce the distance which the winding drum must travel in one hour.

There is some difference of opinion as to the type of escapement best suited for a master clock. When the driving power is constant, there is nothing that can compare for all-around dependability and timekeeping qualities with the Graham dead-beat type of escapement used in International master clocks. This type of escapement was invented by George Graham. It derives its name from the fact that the escape wheel comes to a dead stop at each swing of the pendulum.

Very many other types of escapements have been developed, but the only other one of commercial importance for master clocks is what is known as the gravity escapement. This escapement depends upon the force of gravity to give the pendulum a slight push at each swing or oscillation. This type of escapement is very satisfactory in tower clocks, etc., where wind pressure on the hands, or thickening of the oil caused by low temperatures in the exposed locations of tower clock movements, might cause a varying amount of power to be delivered to the escape wheel.

The balance wheel escapement, or marine escapement, as it is popularly called because of its particular adaptation to clocks used on ships, has found little favor for use in master clocks. This type of escapement requires extra gearing because of the increased number of beats.

Because the oscillations of the balance wheel are governed by a hair spring instead of by gravity, as in the case of the pendulum, such an escapement is readily affected by changing loads on the mechanism. Therefore they are not practical as commercial master clocks which must be adapted to carry electrical contacts and perform other duties.

The driving power of any clock that has a permanent location may be either weights or springs. It is obvious that weights would exert a more even pressure and that the position of the weights (wound up or run down) would not affect the pressure or power. For this reason weights are invariably used on high-grade clocks. If a spring is used to furnish power and it is wound. constantly and evenly, the average power will be practically constant. Our spring-driven master clocks are wound once each minute, to correspond, to the amount which the spring has run down during the preceding minute. Thus they keep very accurate time because the spring tension is kept almost constant.

Every pendulum has a natural period of oscillation. This period is determined by the length of the pendulum and varies inversely as the square of the length. We know from experience and can also figure out mathematically that a pendulum to beat seconds must be about one meter in length. This is termed a 60-beat pendulum because it swings 60 times per minute. This one meter length is measured from the point of suspension to the center of oscillation, which is very close to the center of gravity. The area over which the weight of the pendulum bob is distributed will determine the overall length of the pendulum which usually averages about 45” for a 60-beat pendulum. A 120-beat pendulum oscillates in half the time of a 60-beat pendulum; therefore, it is one-fourth as long as a 60-beat pendulum. Based on these figures, a 30-beat pendulum would be approximately 13 feet long and a 45-beat pendulum would be nearly seven feet long. The 45-beat pendulums are not unusual on tower clocks, but the 30-beat pendulum has never been popular in this country. There are quite a number of 30-beat pendulums in use in England. International [IBM] manufactures master clocks with 60- and 120-beat pendulums. In the past we have manufactured pendulums for 72 and 88 beats. Other things being equal, the fewer the number of swings per minute, the better the timekeeping qualities of the master clock. This is true because the less the number of swings the less chance for errors to creep in.

It has been noted that the longer the pendulum the slower it swings. This fact is used in regulating the clock. If a clock runs fast, the pendulum ball must be lowered in order to lengthen the pendulum.

At first thought, one would naturally assume that a pendulum would require additional time to swing through a wider angle. It is a little difficult at first to realize how a pendulum could swing 12" in the same time it would swing 1". Further study of the pendulum, however, shows that this is practically true. It is the theory upon which nearly all high-grade timekeeping instruments are based. Delving into this assumption a little further, we find that this statement is not 100% correct and that the shorter the distance the pendulum swings, the less the time required for the swing. This error is very small and is what is known as the circular error. Horologists in all ages have tried to overcome this error. They discovered that if the pendulum were caused to swing through the arc of a cycloid (loci of a point on a circle rolling along a straight line) it would oscillate in uniform time regardless of the length of the swing. Various methods had been employed to cause the pendulum to swing through the arc of a cycloid. The most satisfactory one is to use a suspension spring of the proper stiffness and length. This is the principle employed by International.

As gravity is the main factor in controlling a pendulum and as the force of gravity varies with latitude and altitude, a pendulum that is properly adjusted for one location cannot be moved to another and be expected to keep correct time, hence the adjusting screw on the end of each pendulum. Likewise, humidity or density of air affects the pressure on a pendulum, or increases the air resistance and causes an error. Various compensating devices have been developed but none are of commercial importance. They are, however, quite widely used in precision clocks.

One of the first errors in clocks to be corrected is what is commonly termed the temperature error. The pendulum rod had a tendency to expand with increase in temperature, thus causing the clock to run slow. Many types of compensating devices have been invented, but nearly all have now been discarded with the exception of the wood rod with metal bob and the mercurial compensating pendulum. International uses both types. A wood rod expands very little with changes in temperature; therefore, if this is used with a pendulum bob having a small coefficient of expansion one will compensate for the other and the clock should have a very good temperature regulation. The most serious objection to a wood rod is that its dimensions are affected by humidity.

The mercurial compensating pendulum consists of a steel rod supporting jars filled with mercury. The jars are supported at their base. Then the steel rod lengthens because of an increase in temperature, the base of the jars is lowered. For the same reason the mercury expands so that the column lengthens and raises the center of gravity of the mercury. Thus the center of oscillation is kept in the same place. If the pendulum is properly compensated according to this plan, the clock will keep correct time regardless of the temperature. This type of pendulum is not affected by humidity.

It is interesting to know that pendulum clocks cannot be installed in some high buildings because of the sway caused by wind, pressure or vibration. This would cause the clock to run erratically. If the sway of the building should synchronize with the pendulum, the clock would stop. Occasionally this condition can be rectified by installing the clock on a wall at an angle of 90 degrees to the prevailing sway of the building.

As stated before, International makes two types of master clocks with respect to driving power, namely, the spring-driven and the weight-driven. The escapement, gears, and pendulums of these clocks are identical, the only difference is in the method of applying the power to the escape wheel. The spring-driven clock is wound by an electromagnet. A small coil or helical spring is placed on the center shaft and furnishes the power to keep the clock going, but while doing so it runs down one minute with each revolution of the second hand. At the completion of the minute, when the minute impulse contact closes, a circuit is completed to the electromagnet, thus attracting its armature and rewinding the master clock an amount equivalent to what it has run down the preceding minute. As long as the electric power for winding is available, the clock will be supplied with an average uniform spring tension and no errors will creep in because of irregularities in the power supply. However, if the winding power is interrupted for any length of time, the main spring will gradually lose its tension and less power will be applied to the escape wheel. If the power is interrupted for a sufficient length of time, the spring will become completely unwound and the clock will stop. International spring-driven master clocks will run for nearly two hours after the power is interrupted.

The International weight-driven master clock is the highest grade of commercial time piece obtainable. It is designed to run eight days with one winding. The weights supply power to the escape wheel to keep the pendulum swinging.

The tension is, therefore, exactly the same regardless of whether the master clock is wound up or nearly run down. Differential gears are used to furnish power to the escape wheel while the clock is winding. Ball bearings are used in six different places on the winding drum and in two places in the movement in order to reduce friction to a minimum. The weights are restored to a wound-up position by a motor which performs this operation with the least possible disturbance to the movement. This [sic] is no jar as is the case when winding with an electromagnet. The motor is of the universal type and will operate equally well from either DC or AC. An automatic switch is provided which cuts in the motor after the weights have run down a distance equivalent to one day's time of operation. If power is not available for winding, the switch remains closed, thus insuring that the master clock is wound immediately after restoration of power.

Contacts in a master clock are necessary in order to control and supervise secondary units. The contacts on International master clocks are operated from an auxiliary shaft independent of the time train. This practice makes possible heavy mechanically operated circuit closers, which might more properly be termed switches, instead of the usual delicate contacts. Special purpose contacts such as Westminster, Hour Strike, etc., are sometimes placed on master clocks.

Impulse Accumulator

An impulse accumulator may be added to a weight-driven master clock. It is a device which counts the number of minutes the secondary units have lost due to power failure. It then provides a means of sending out these lost impulses, thus bringing the secondary units to correct time. It will take care of a maximum of 12 hours of interruptions, and start restoring the secondary units back to normal immediately after the power is returned. It operates the secondary units at a speed of 30 times normal running speed.

Control Relays

The purpose of a relay is to permit a small amount of current to control larger amounts. If the size of the contacts in a master clock were not limited in order not to affect the timekeeping qualities of the master clock, relays in a clock system would not be necessary. As it is, the contacts of the master clock carry only enough current to energize the coils of a relay. The contact points of the relay, which are much heavier, carry the load of the secondary apparatus.

There are thousands of types of relays on the market, but regardless of style, type or make, they invariably perform one of two functions or a combination of both. They will either open a circuit, close a circuit, or do both. These services may be varied by using additional contacts; that is, if two sets of contacts are used they may control two entirely independent circuits.

International makes a wide variety of relays. Where the volume of business does not warrant the purchase of equipment necessary to manufacture them, some special purpose relays of other manufacturers are used. These relays are designed for operation on AC or DC and any voltage up to 110 volts.

Relays for controlling clock systems are usually installed in separate cabinets and are called master relay equipment, distribution relay equipment, etc., as the case may be. Master relay equipment is that relay equipment which operates directly from the master clock. Distribution relay equipment is that equipment which receives its operating power from the master relay equipment and controls additional distributing circuits.

When the operating power is direct current, the relay cabinet consists of the necessary relays, fuses, switches, and connectors mounted on an ebony asbestos board and installed in a metal cabinet or in the master clock or program case. When the operating power is alternating current, the relay cabinet, in addition to the above named equipment, also includes the necessary transformers and rectifiers. The transformers are used to step down the 110 volt AC commercial supply to the operating voltage of the system. The rectifiers are used to change the alternating current to a pulsating direct current, the better to operate the electromagnets in the clock system.

All master relay cabinets for International supervised systems are equipped with a double pole double throw switch, which is termed the “run” and “advance” switch. This switch is wired to the master clock in such a way that when in the “run” position the system will operate normally; that is, the secondary units will be advanced one minute for each minute of the master clock. When the switch is thrown to the “advance” position the control circuit is changed so that the master relay will operate every two seconds, or each time the two seconds contact closes. This advances the system 30 times its normal speed. This switch is useful in setting the system after a long power lapse where an impulse accumulator is not incorporated in the master clock. It is obvious that this switch is unnecessary when an impulse accumulator is used, as the impulse accumulator automatically does the same thing the switch does manually.

It will be noted that the distribution relay cabinet is equipped with two relays whereas a master relay cabinet has only one relay. In the discussion of supervised time systems, it was pointed out that a master clock controlled one switch of a three wire transfer system. It is obvious that the capacity of this switch is limited; thus it is able to accommodate only one circuit. Distribution relay cabinets are used only where there are two or more circuits. The extra relay, therefore, performs the same service to the extra circuit as the switch on the master clock performs to the main circuit.

International manufactures what is termed a duplicate master relay cabinet. This relay cabinet is for use with a duplicate set of master clocks and contains all of the important equipment, such as transformers, rectifiers, etc., in duplicate. Double throw switches are provided so that any combination of these units including master clocks may be used.

Secondary Clocks

In reality any form of time indicating, time signaling, or time recording device connected to an electric time system is a secondary unit. However, by custom we refer to secondary clocks as those clocks which are used time indicating only.

The style of the case and the size of the dial may vary but the underlying principle of all International minute impulse secondary clocks is exactly the same. The case or general appearance of secondary clocks may be almost anything. International standard line includes marble dial clocks, dial clocks, cast bronze cases, spun cases, wood cases, etc. Dials may be of any material and of any finish desired. Likewise, the numerals and hands may be designed to suit the fancy of the purchaser.

The mechanism operates on the ratchet and pawl principle; that is, an electromagnet energizes a spring which in turn operates a pawl which advances a ratchet and moves the hands. The hands are connected directly to the ratchet. Usually there are 60 teeth in the ratchet, or one for each minute during the hour.

International manufactures three types of impulse secondary units. The one most commonly used is known as the 561 movement. It is designed to handle lightweight hands not exceeding those for a 24” dial. It is practically silent in operation and very efficient, as it requires only a small amount of current.

The list [i.e., model or type] 562 secondary movement is much heavier in construction and designed for operating heavier hands up to approximately 30” dials. The principle of operation is slightly different in that the armature operates upon the reciprocating principle instead of the rocking or oscillating principle used in the 561 movement.

The list 563 movement is a heavy-duty movement for operating heavy cast metal hands and hands for large-sized clocks. It is equipped with a geared retard which lets the hands move forward slowly.

When the dials are large, or the hands heavy, or exposed to air currents, a motor-drive secondary movement is recommended. International makes two types of motor-drive secondaries. The principle of operation is that the impulse from the master clock energizes a relay which in turn starts the motor to drive the hands. The motor picks up its power locally. There is practically no limit to the size of hands that may be driven from this type of movement.

Quite frequently, for large size dials, a tower clock movement with an electrical escapement is used. The tower clocks are complete clocks with self-contained power, gears, etc., with the exception of the escapement and pendulum. An electromagnet is installed on the tower clock movement in such a position that when it receives an impulse from the master clock it releases the stored-up power of the tower clock and lets the hands advance one minute.

When secondary clocks are operated each second, instead of each minute, they are termed seconds-beat secondaries. The mechanism of seconds-beat clocks is practically the same as that of a 561 movement with the addition of a means of resetting the hands to zero. A seconds-beat secondary performs the same function as a stop watch.

The locations and installation of the secondary clocks are very important. Ordinarily one does not easily see things that are higher than an angle of 30 degrees above the horizontal. In a well designed room, pictures and the like are kept fairly well down on the wall, fully in the line of vision. Clocks should be no exception to this general rule. They should be placed so that they are easily visible, usually on the walls opposite the windows so that the person reading them will not have to look towards the light. There is no reason why International secondary clocks must be placed within easy reach for resetting or repairs as they never require individual setting, this being done automatically by the master clock.