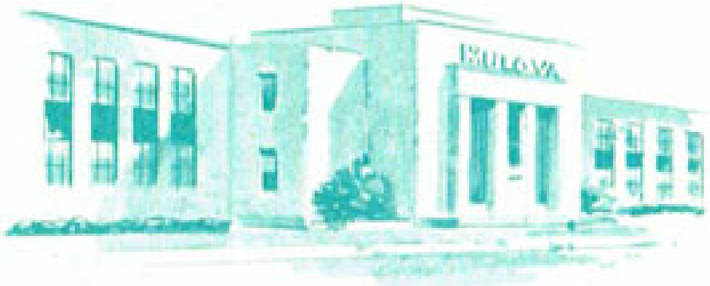
FACTS ABOUT ACCUTRON®

BULOVA

WATCH COMPANY, INC.



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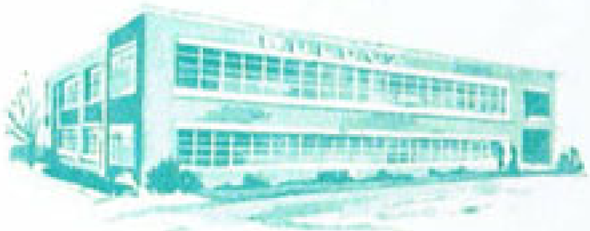
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FACTS ABOUT ACCUTRON TIMEKEEPING DEVICES

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FOREWORD

The name "ACCUTRON" denotes a man's wrist timepiece, among other Bulova electronic products. It is the *first* and *only* watch-size timepiece, including those powered by a battery, which does not use a balance wheel and hairspring. Instead, the ACCUTRON mechanism has a tuning fork as the timekeeping element. The tuning fork is driven with energy from a tiny Power Cell, or battery, by means of an electronic circuit. The vibratory motion of the tuning fork is converted into rotary motion, for turning the time-indicating hands, by means of a simple but incredibly small mechanism.

The outstanding characteristic of the ACCUTRON timepiece, in comparison with traditional watches, is its accuracy of timekeeping. A tuning fork is *inherently* accurate, unlike the balance wheel and hairspring. Also, having no pivots or bearings, its accuracy is independent of the effects of lubrication and wear. It is this uniqueness which permits the Bulova Watch Company to give a written guarantee of specific accuracy with each ACCUTRON timepiece. This guarantee states that it will not gain or lose more than a minute a month in normal use as a wrist timepiece.

ACCUTRON was conceived, developed, designed and manufactured entirely within the organization of the Bulova Watch Company, Inc. It first made its appearance in the jewelry stores in November 1960. Unlike many other space-age devices, the ACCUTRON timepiece was developed solely as a consumer item (at Bulova expense), although it has since been used in many important applications in the United States' exploration of outer space. New applications are constantly being found where its unusual combination of characteristics such as accuracy of timekeeping, tiny size and long running time on a self-contained source of power are advantageous.

Because the ACCUTRON timepiece is so completely unlike conventional watches, many owners have expressed an interest in detailed information that would enable them to obtain the fullest benefits from its use. Part I, *Characteristics of* ACCUTRON, and Part II, *Instructions and Hints for the* ACCUTRON *Owner*, have been written for this purpose.

In addition, many owners, while enjoying the advantages of their unique timepiece, want to know more about the scientific and engineering aspects of ACCUTRON. Part III, *The* ACCUTRON *Mechanism—How It Operates*, has been included in this *Manual* for the technically-minded user.

the ACCUTRON *guarantee of timekeeping*

The ACCUTRON timepiece is guaranteed by Bulova not to gain or lose more than one minute a month in normal use as a wrist timepiece. For one full year from date of purchase and without charge, it will be adjusted to this tolerance, if necessary, as stated in the following guarantee:

THE ACCUTRON® GUARANTEE

The ACCUTRON timepiece is guaranteed internationally by Bulova not to gain or lose more than one minute a month in normal use as a wrist timepiece, and is guaranteed against all damage and defects, except loss, fire and theft. For one full year from date of purchase from an authorized ACCUTRON jeweler, it will be repaired, serviced or adjusted, if necessary, without charge, if returned to the authorized ACCUTRON jeweler from whom it was purchased, or to any Bulova factory, office or distributor.

NOTE: Authorized ACCUTRON jewelers have been instructed to complete, within thirty days of your purchase, a registration card that details specific information concerning your ACCUTRON timepiece and to send it to Bulova Watch Company, Inc., Bulova Park, Flushing, New York 11370.

I characteristics of ACCUTRON

timekeeping — ACCUTRON *vs. conventional watches*

The performance of any wrist timepiece is judged by the way it keeps time in actual use. Performance depends upon the extent of the timepiece's immunity to the many disturbing environmental factors encountered in use. The ability to cope with these detracting influences varies considerably from watch to watch. In conventional timepieces it depends upon:

1. The excellence of its initial construction and factory "adjustment."
2. The skill with which the most recent repair was made.
3. The amplitude of oscillation of the balance wheel, which depends principally upon the state of the lubrication.

In the ACCUTRON movement, on the other hand, the timekeeping capability is governed principally by the "designed in" characteristics of its tuning fork. Also, since the tuning fork has no pivots or bearings, its timekeeping is free from the effects of lubrication.

A quantitative comparison of the performance capabilities of ACCUTRON timepieces and conventional watches can be made only by laboratory tests, in which identical conditions of operation can be maintained. For such comparisons the Watch Timing Tests of the Official Swiss Testing Bureaus are very useful. Among these tests is one for wrist "chronometers." These watches are regarded as the most accurate conventional watches available. Watches fulfilling the requirements of this 15-day test are awarded individual certificates by the official testing agency. Should a watch meet somewhat closer performance criteria, the award is issued with "mention" for particularly good results. The performance criteria which must be met to qualify for such distinguished awards are shown in Table I. Also shown are the corresponding characteristics of the ACCUTRON movement, as established by design or manufacturing tolerances.

From Table I the relative capabilities of the ACCUTRON timepiece and the *best* conventional watches, under laboratory conditions, are clearly evident. In normal service, the superiority of ACCUTRON performance is still more striking.

A conventional watch which gains or loses as little as a minute a month in actual use is very exceptional; in other words a "freak." To provide such performance in quantity production would be fundamentally impossible. For ACCUTRON, however, that same minute a month is a *maximum* error. Achievement of such accuracy is the direct result of the basic superiority of the tuning fork over the balance wheel and hairspring. It is this difference which has made possible Bulova's guarantee that ACCUTRON will not gain or lose more than a minute a month in normal use as a wrist timepiece. This guarantee is a new criterion for judging watch performance.

Table I.

Comparison of Timing Tolerances for Wrist "Chronometers" with Inherent Performance Characteristics of ACCUTRON

Characteristic	Tolerance for Chronometer	Tolerance for Chronometer with mention	Inherent performance characteristics of ACCUTRON
	(all rates seconds per day)		
1. Regulation — Mean rate in 5 positions at room temperature.	−3 to +12	−1 to +10	−2 to +2
2. Mean variation in rate for above test.	3.2 max.	2.2 max.	less than 1
3. Largest variation in rate for above test.	9	6	less than 1
4. Rate difference between 6 up and dial up.	12 max.	8 max.	5
5. Largest difference in rate for any of the 5 positions tested and mean daily rate.	18	12	4
6. Rate-Temperature Coefficient in sec/day/° C from 4° C to 36° C.	1 max.	.6 max.	.3 max.
7. Recovery (change in rate as result of exposure to temperature test).	9 max.	5 max.	less than 1

the effect of position on ACCUTRON

One of the major factors contributing to the timekeeping accuracy of the ACCUTRON movement is its small and predictable position error. The tuning fork has a basic position error which is completely predictable in amount and direction. Furthermore, this position error is independent of tuning fork amplitude.

When the long dimension of the tuning fork is horizontal, the frequency of vibration is the same, whether the tines of the fork are alongside each other or one above the other. In most ACCUTRON models, the tuning fork is mounted along the 12-6 axis of the movement. Therefore, the rates in dial-up, dial-down, 3-down, and 9-down positions will all be precisely the same.

When the long dimension of the tuning fork is vertical with the tines down, which is the 12-down position in most ACCUTRON models, the effect of gravity causes a slightly higher tuning fork frequency. In this position the rate is 5 seconds per day faster than when the fork is in a horizontal position. Conversely, when the fork is vertical with the tines up, the frequency of the tuning fork will decrease, causing a rate 5 seconds per day slower than when it is in a horizontal position. This is the 6-down position in most ACCUTRON models, and is rarely experienced when the watch is worn on the outside of the wrist.

This extremely small position error is taken into consideration in the regulation of ACCUTRON movements at the factory. It is regulated for best timekeeping when worn on the outside of the wrist. It is recommended that when the owner desires to wear his ACCUTRON timepiece on the inside of the wrist (making the 6-down position occur more frequently), it should be regulated 3 seconds per day faster than the original factory adjustment.

the effect of temperature on **ACCUTRON**

The elements in the ACCUTRON electronic circuit are chosen to provide for reliable performance under temperature extremes from 20° F to 120° F (–7° C to + 50° C). Outside this range, performance or timekeeping ability may be unsatisfactory. It should be remembered that this will have no effect on operation under normal conditions, since the ACCUTRON timepiece is meant to be worn on the wrist, and when it is, will be within a few degrees of body temperature, even in extremely cold or hot climates.

The effect of temperature on its rate is considerably less than for normal high-grade wrist watches. If removed from the wrist at night, the temperature of the timepiece may change considerably. However, the net effect upon the daily rate is small since the temperature error is small by design, and the exposure to the "abnormal" temperature does not usually exceed 8 hours daily.

the effect of shock on **ACCUTRON**

The ACCUTRON timepiece, on the wrist of the user, is completely immune to the shocks of gardening, playing golf or baseball, hammering, etc. Repeated blows, directly on the side of the case, can temporarily affect the operation of the mechanism and cause a change in time. However, it is so protected, when worn in a normal manner on the outside of the wrist, that repeated accidental bumping, sufficient to affect the timepiece, is impossible.

Various means have been included in the design of the ACCUTRON movement to minimize the possibility of damage if the timepiece is dropped. The most sensitive parts of an ordinary watch are the pivots on the balance wheel staff. Conventional watches are shock-protected by special spring mountings for the jewels for these pivots. In the ACCUTRON movement, shock protection has been provided by using a shock bridge and stops to limit the maximum movement of the tuning fork tines, and by a guard surrounding the index and pawl jewel fingers.

A shock great enough to break a balance wheel pivot in a conventional "shockproof" watch may, in ACCUTRON, derange the indexing mechanism. Restoring the mechanism to perfect operating condition requires only minor adjustments by the repairman, in comparison with the major operation of replacing a balance staff.

Everything possible has been done to protect the ACCUTRON mechanism from the shocks of normal use. However, like any fine precision instrument, it should be treated with the respect it deserves.

the effect of vibration on ACCUTRON

The ACCUTRON movement, if mounted directly on a vibrating structure or maintained in contact with it, may be affected by vibration. The effect, if any, would depend upon both the frequency and direction of the vibrations. However, the wrist of the user cushions the ACCUTRON timepiece, so that direct exposure to vibrations which can affect the tuning fork is impossible. The use of power hedge trimmers, power mowers, sanders and other such vibrating equipment will have no effect on an ACCUTRON timepiece worn on the wrist.

the effect of magnetism on **ACCUTRON**

ACCUTRON timepieces are less affected by the magnetic fields usually encountered in normal service than are conventional "anti-magnetic" watches. The criterion for an "anti-magnetic" watch is that, when subjected to the influence of a magnetic field with a strength of 60 gauss and then removed from this influence, it shall operate without being affected more than 15 seconds per day. The ACCUTRON timepiece easily meets this specification, changing rate only a few seconds per day.

The ACCUTRON timepiece should not be deliberately exposed to an extremely high strength magnetic field, as in a demagnetizer or a strong permanent magnet, since it is obvious that it would be possible at some level of field strength to demagnetize the permanent magnets on the tuning fork. If an ACCUTRON timepiece is accidentally demagnetized it will stop, and the tuning fork must be replaced or returned to Bulova to be re-magnetized.

the effect of altitude on **ACCUTRON**

Its rate, like conventional watches, is affected by the changes in barometric pressure associated with changes in altitude. In conventional watches, other effects are so large that rate changes of several seconds per day are rarely noticed. In ACCUTRON, although the rate change with altitude is about the same as for conventional watches, the effects of pressure changes on its performance are more likely to be apparent because of its very small rate of gain or loss.

The ACCUTRON tuning fork will gain at increasing altitudes. Up to about 15,000 feet the effect is to gain 3 seconds per day for each 5000-foot increase in altitude. This effect is caused by the change in density of the moving air column which, in principle, forms part of the mass of the vibrating tuning fork.

This effect does not normally result in any significant problem. The ACCUTRON owner who is permanently located in an area substantially above sea level may find it necessary to return his timepiece to the local jeweler for regulation, to correct for a gaining rate. Temporary exposure, such as in air travel, has a very slight effect. For example, a 6-hour flight at a "cabin altitude" of 5000 feet (which is conventional) would cause an ACCUTRON timepiece to gain ¾ of a second more than if the owner had remained on the ground at sea level.

jewels in ACCUTRON

The number of jewels in a watch movement has traditionally been, to the consumer, an indication of quality. However, since the ACCUTRON movement uses an entirely new system of timekeeping, there is actually no basis of comparison with conventional watches. As a matter of information, the ACCUTRON movement has 17 points of possible wear, all protected by jewels.

waterproof cases

Most ACCUTRON models are of standard "waterproof" construction. The primary purpose of this case construction is to prevent trouble due to accidental immersion and to perspiration, dust, etc. entering the case. Each "waterproof" ACCUTRON timepiece is individually tested before it leaves the factory to assure that it does not leak. Some users wear these timepieces while bathing and swimming. However, deliberate subjection of a fine timepiece to the hazards of such exposure is not encouraged by Bulova. The case construction required to provide protection for activities such as skin diving is somewhat undesirable for normal use because of styling considerations and has therefore not been employed in any ACCUTRON models.

instructions and hints for the ACCUTRON *owner*

setting the hands

Frequent setting of the ACCUTRON timepiece is not required because of its unusual accuracy. Since the setting crown is seldom used, it has been placed on the back of the ACCUTRON case. Its position is shown in Fig. 1. Lifting the setting handle to an up-right position, using the fingernail (see Fig. 2), engages the setting mechanism. When the setting handle is in the up-right position, the hour and minute hands may be set by turning the handle in either direction (see Fig. 3).

Most ACCUTRON models are provided with a spring which returns the setting handle to the flat position and at the same time disengages the setting mechanism after the hands have been set. After returning the handle to the flat position on models *not* provided with the spring, it is necessary to press in the crown, until a slight snap indicates that the setting mechanism has been disengaged. This is the same as pressing in the crown of an ordinary watch after setting. If the setting mechanism is not disengaged, the hour and minute hands will not turn.

Fig. 1
Rear View of ACCUTRON Case

The sweep second hand of the ACCUTRON timepiece continues its rotation while the minute and hour hands are being set, so that an exact number of minutes or hours may be added or subtracted. This feature is particularly useful when traveling from time zone to time zone or when changing to or from daylight saving time. If desired, the second hand can be set approximately on time by removing the Power Cell and replacing it at the proper time. With practice, this can result in a fairly accurate setting. This procedure, although relatively difficult, is the only way to accomplish a result which is not intended as a feature of this timepiece.

The above information applies to all ACCUTRON timepieces except special purpose "hack" models, such as the Astronaut and the Railroad models. These special models provide for second-setting by stopping the timepiece while the hands are being set. Those requiring the second-setting feature for some special purpose may have it added to any ACCUTRON model (at extra cost) by sending it to the Bulova Service Department, through the jeweler from whom it was purchased.

Unlike the gears in other precision mechanisms, watch gears are deliberately designed to provide a substantial amount of "backlash." This backlash is a basic requirement for reliable operation—not an unavoidable defect or an indication of inferior workmanship. The user is not usually aware of backlash in the gear train of a conventional watch. The ACCUTRON timepiece, unlike conventional watches, has no mainspring to keep the gears under tension at all times, thus masking the effects of backlash. The result is that ACCUTRON exhibits characteristics during setting which are not typical of conventional watches. For example, when setting the minute and hour hands ahead, the sweep second hand will appear

Fig. 2
Lifting the Setting Handle

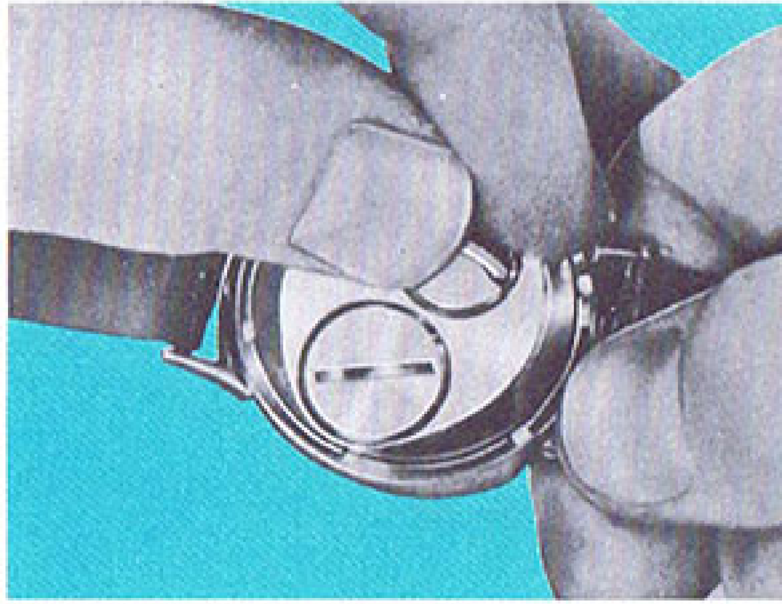


Fig. 3
Setting the Hands

to jump ahead 5-6 seconds and may then pause for the same few seconds before resuming its rotation. This is merely visual evidence of the backlash in the ACCUTRON gear train—the second hand having been forced ahead of the gears driving it. Once the gears have had sufficient time to "catch up" (5-6 seconds), the sweep second hand will resume its rotation and will not have gained or lost time in relation to another timepiece.

Backlash in the ACCUTRON gear train results in another characteristic unlike conventional watches. A sharp tap on the side of the ACCUTRON case, in the appropriate direction, will cause the sweep second hand to advance some 5 to 6 seconds, after which it will pause for the same 5 to 6 seconds before resuming its normal rotation. The net effect is, of course, zero since the sweep second hand resumes exactly its previous indication in relation to correct time. This "phenomenon" is a further evidence of backlash in the gears—not an indication that the mechanism has stopped.

The following simple procedure for setting the ACCUTRON timepiece permits exact synchronization of the minute and sweep second hands:

1. Turn the minute hand ahead of the desired minute marker, then turn backward to position it exactly over the desired marker when the sweep second hand reaches the "60" second position.

2. After step 1, turn the setting handle slightly forward before returning it to the flat position, making certain not to turn it far enough to move the minute hand forward.

The first step takes the backlash out of the gear train, permitting the minute hand to start immediately, when the setting mechanism is disengaged. The second step takes advantage of the backlash between the setting stem and the mechanism which is turned by it—permitting the setting stem to turn slightly in either direction, as the setting handle goes down, without turning the minute hand.

changing the ACCUTRON *power cell*

Each ACCUTRON Power Cell is clearly marked "ACCUTRON, $1.50 RETAIL" for identification. See Fig. 4 (earlier cells were marked "W-2"). This cell is guaranteed to operate the ACCUTRON timepiece for a minimum of one year. Annual replacement will prevent the inconvenience of having the timepiece stop. The performance of ACCUTRON is practically independent of the energy remaining in the Power Cell. If the Cell is not replaced before exhaustion, the timepiece will simply stop—perhaps after several hours of intermittent operation.

Replacing the Power Cell is a very simple operation, which may be performed by the owner. The services of a watchmaker are not required. The following procedure should be followed:

1. Wipe the back of the case to remove any loose material near the Cell cover (to prevent the entrance of dirt when the cover is removed).
2. Unscrew the Cell compartment cover using a U.S. dime (see Fig. 5).
3. Turn the timepiece over and the old Cell will fall out.
4. Place a fresh Cell in the compartment with the smaller side down.
5. Screw the cover securely in place to assure a water-tight seal.

Fig. 4
The ACCUTRON Power Cell

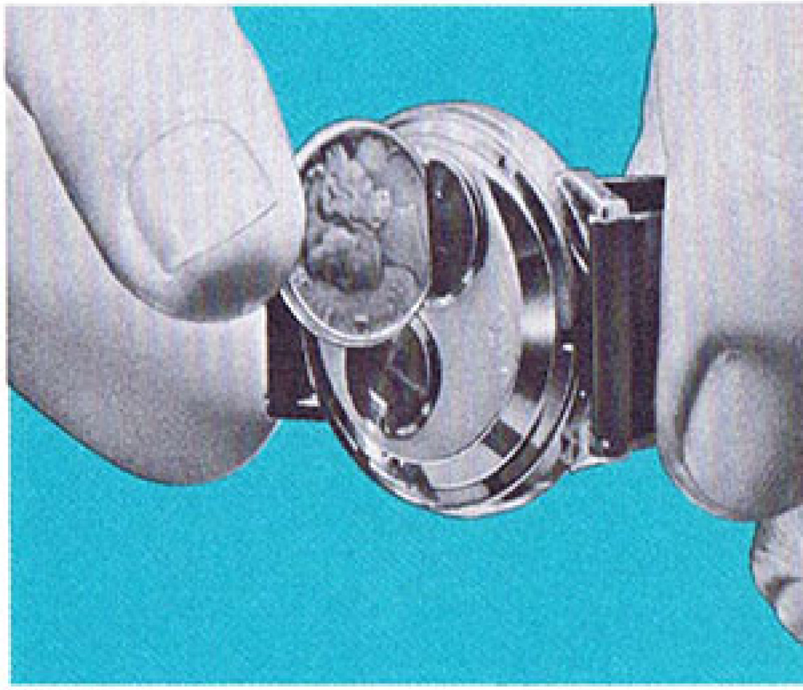


Fig. 5
Removing the Power Cell Cover

WARNING: *Substitute cells should never be used in place of the Genuine* ACCUTRON *Power Cell. A substitute cell may seriously damage the* ACCUTRON *movement.*

The ACCUTRON Power Cell, unlike hearing-aid cells having a similar external appearance, uses a different electrolyte and special sealing techniques to prevent the leakage of corrosive materials which can damage the ACCUTRON movement. Furthermore, the ACCUTRON Power Cell is specifically designed to supply a tiny amount of power for well over one year, whereas a hearing-aid cell—designed to deliver a relatively large amount of power for a short time—will usually fail in the ACCUTRON movement after 3-4 months.

Shelf-life of the ACCUTRON Power Cell presents no problem. Cells which have been in stock (unused) for 2-3 years will operate the ACCUTRON timepiece for a minimum of one year—as guaranteed.

the ACCUTRON *regulating system*

The ACCUTRON timepiece, unlike conventional watches, is fitted with a *calibrated* regulating system which eliminates "cut-and-try" adjustment in those instances where regulation is necessary. Most ACCUTRON timepieces will keep time within one minute per month, as guaranteed, without regulation by the jeweler. An exception occurs for the occasional owner who wears it on the inside of the wrist. This practice requires regulation by the jeweler, otherwise the timepiece can be expected to lose more than a minute per month. The reasons for this are explained on page 8.

BULOVA–

Timekeeper for the World

A Profile of a Dynamic Company Dedicated to Progress

IN 1875 Joseph Bulova, a 23-year-old immigrant from Czechoslovakia, started a small jewelry shop on New York City's Maiden Lane. An appreciation of quality and the old-world skills he had learned as a youth, were for a while the major assets of the firm. Yet from it has grown the Company that is today the world's largest manufacturer and seller of fine jeweled-lever watches. Over 50 million Bulova watches have been worn with pride the world over.

It was a dream of the Company's pioneers — Joseph Bulova and his son, Arde Bulova — to produce fine watches at prices everyone could afford. Under present management those goals are being achieved in the Company's busy plants in Jackson Heights, Woodside and Sag Harbor, all on Long Island, New York; in Providence, Rhode Island; in Toronto, Canada; at Bienne and Neuchatel, Switzerland; and Pforzheim, Germany.

Nearly 600 different models of watches and timepieces are currently available. The most unusual of all is the Accutron® electronic wrist timepiece, introduced worldwide in 1960.

Accutron timepieces incorporated the first major change in personal timekeeping instruments in over 300 years. Even the sound of its electronic time is different. The "ticking" associated with conventional mechanical or electric watches has been replaced by the soft "hum" of a vibrating tuning fork—dividing each second into 360 equal parts as compared to five in conventional watches. This tuning fork and a transistorized electronic circuit combine to make an instrument so accurate — it is guaranteed neither to gain nor lose more than a minute a month in normal use as a wrist timepiece — yet so reliable and durable that it has been used for timing applications in four families of satellites. Space scientists guiding these projects requested Bulova engineers to provide a timing device that was accurate, reliable, small, of long duration, with a low power drainage (8 millionths of a watt) and capable of surviving the effects of a rocket launching and the conditions of outer space. Accutron based satellite timers more than met the need and were selected and used on Explorer, Tiros, Telstar and Syncom earth satellites.

In World War II precision machines operated by Bulova craftsmen produced military watches and other timepieces as well as aircraft instruments, bomb fuzes, fire control telescopes and instruments, and torpedo parts. From this start have grown facilities for development and manufacture of important contributions to national defense, industry and space exploration programs. Three Bulova divisions — Systems and Instruments Division (including Bulova Research and Development Laboratories), Electronics Division and Watchmaster Products Division — supplement the horological engineering and manufacturing staff of the basic Bulova organization and provide technical talent, equipment and proven capability in these areas.

(over)

As World War II drew to a close, Bulova established a unique program for helping in the rehabilitation of wounded war veterans. The Joseph Bulova School of Watchmaking, located in Woodside, New York, after two decades of service in this area, has earned a world-wide reputation as a rehabilitation center second to none in the training of the physically handicapped in the skills of watch repair and precision instrument making.

Bulova's unique capabilities in blending the precision skills of watchmaking with its other specialized technologies gave birth over a decade ago to a complete assortment of consumer electric products that range from — clock radios, watch radios, radio-clocks to solid-state entertainment units topped by Bulova stereo-phonographs.

New inexpensive selections of Caravelle® fashion-oriented jeweled-lever wrist watches, and pendant style Caravelle Watch Charms have earned considerable attention among quality watch purchasers in the lower price range. Also under the trademark Caravelle, Bulova recently marketed a broad grouping of decorator clocks designed for home and office.

During the years ahead "Bulova Quality" will be continually created by Bulova craftsmen the world over. As Harry B. Henshel, president of Bulova Watch Company, Inc. says, "Excellence is our means to an end — and the end is excellence."

Regulation of ACCUTRON, although simple, is not a "do-it-yourself" operation. It requires the services of a watchmaker, who has the necessary equipment and skill to safely open the waterproof case, perform the necessary operation and re-close the case without damage—properly sealing it to assure that it has remained waterproof. However, an understanding of the ACCUTRON regulating system permits the owner to appreciate what is involved, if regulation of his timepiece should be necessary.

Unlike conventional watches, the basic timekeeping accuracy of the ACCUTRON tuning fork is such that regulation for errors in timekeeping in excess of a few seconds per day is *never* necessary. Timekeeping errors as great as, say, 30 seconds per day, are an indication of mal-functioning—requiring repair, not regulation.

The method of changing the rate at which an ACCUTRON timepiece runs is to vary the frequency of the tuning fork. Regulation is accomplished by means of two tiny weights, which are attached to the tuning fork cups. These weights—or regulators—are located near the edge of the movement at the 12-position, as shown in Fig. 6. Like the regulator of an ordinary watch, these regulators are friction fit, and can be rotated. Rotating one of these regulators alters the center of gravity of the fork, and causes ACCUTRON to run faster or slower, depending upon the direction in which it is moved.

Each regulator is serrated to form 7 divisions (4 projections and 3 indentations). Each of these divisions is equal to 2 seconds per day of correction. In other words, rotating one of the regulators changes the rate of the ACCUTRON timepiece by 2 seconds per day for each division it is moved. The amount that a regulator is rotated can be easily gauged by reference

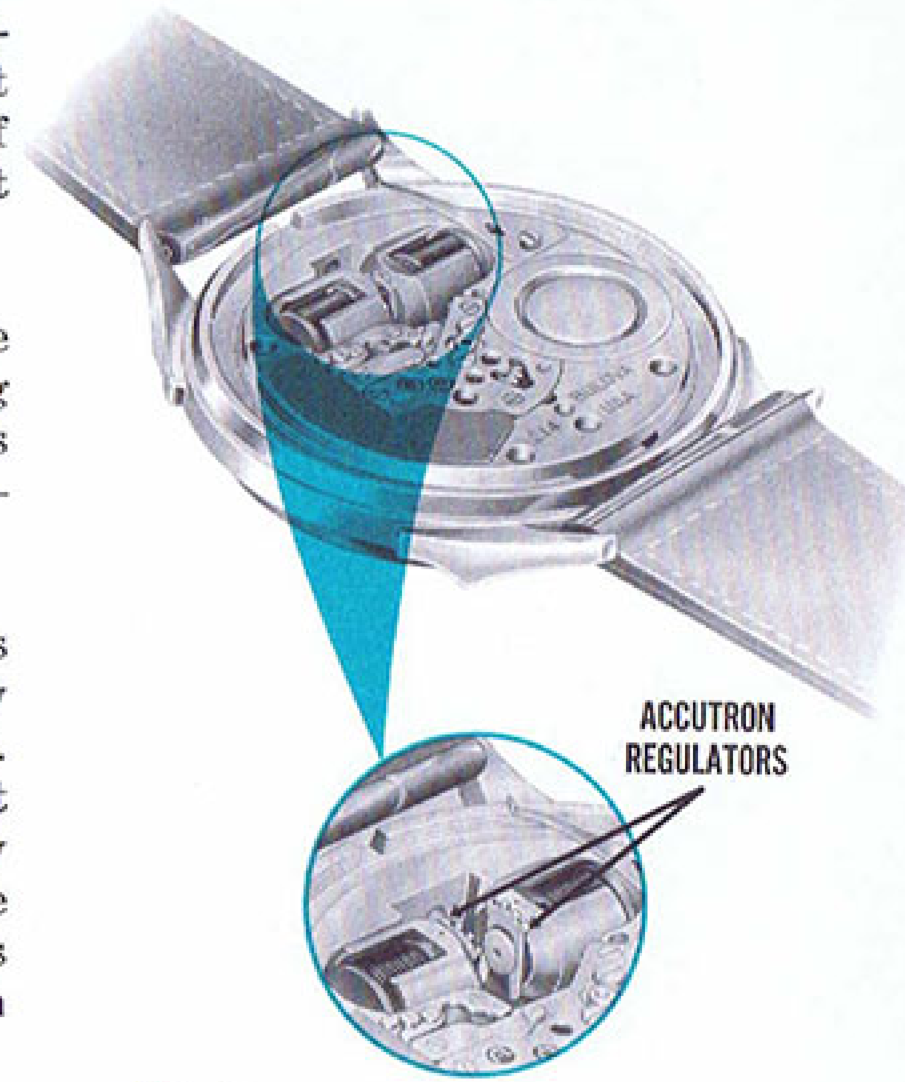
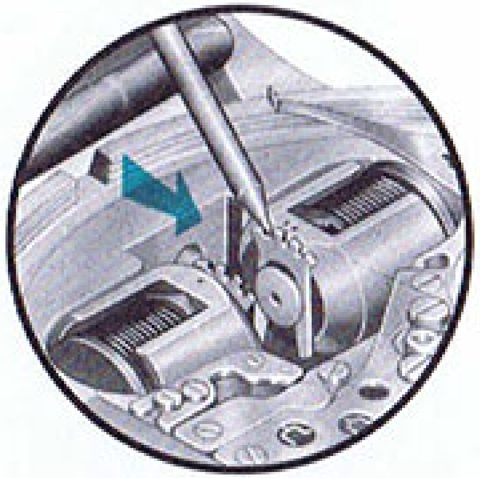


Fig. 6
Rear View of ACCUTRON Movement Showing Regulators

TO REGULATE 2 SECONDS PER DAY SLOWER, EITHER REGULATOR IS MOVED ONE DIVISION OUTWARD AS SHOWN.



TO REGULATE 2 SECONDS PER DAY FASTER, EITHER REGULATOR IS MOVED ONE DIVISION INWARD AS SHOWN.

Fig. 7
Regulating Procedure for ACCUTRON

to the dot on the top of each cup. The regulating procedure is illustrated in Fig. 7.

The ACCUTRON calibrated regulating system permits the jeweler to correct the rate of any ACCUTRON timepiece which has been observed to gain or lose a known number of seconds per day. The occasional ACCUTRON timepiece which requires regulation to reduce a gain or loss of time in excess of the guaranteed maximum of a minute per month can obviously be returned promptly to the customer, without the lengthy period of checking required for the "cut-and-try" regulation of conventional watches.

checking ACCUTRON *timekeeping*

The average ACCUTRON user, interested in time to the nearest minute, checks it occasionally against time signals such as the hourly "beeps" on some television or radio broadcasts. The occasional ACCUTRON owner who is interested in maintaining a day-to-day record of timekeeping to the second may experience difficulty in obtaining *accurate* time for such checking. In the many areas where precise time signals are not available by telephone, the only source of correct time to the second is provided by the precise time signals broadcast by government-operated short wave radio stations.

The difficulty in obtaining time which is accurate to the second is not generally recognized. Although some commercial radio stations provide a *precise* time signal hourly, many such signals are not sufficiently accurate for checking the performance of the ACCUTRON timepiece. The various clocks, chronometers, etc., in jewelry store windows, indicate "correct time" only for those interested in time to the nearest minute. Even the large pendulum clocks seen in many areas of the United States, prominently displaying "U.S. Naval Observatory Time," are only approximately correct. These clocks are controlled by a "master" clock which is manually corrected once each day. This "master," in turn, corrects local clocks hourly. Such clocks are sometimes "off" as much as a minute—errors of 15-30 seconds being very common. Obviously, any precise timepiece (such as ACCUTRON), if compared with such inaccurate time "standards," will seem to vary widely in timekeeping.

servicing and repair of ACCUTRON

Every possible effort has been made in the design and construction of the ACCUTRON mechanism to reduce the need for servicing or repair. In particular, proper design and execution of the tiny index wheel and the associated indexing mechanism have resulted in a system which has shown *no* progressive wear or deterioration. The life of the tiny index wheel teeth appears to be completely indefinite. Elements of the electronic circuit have likewise been so chosen that their useful life is also indefinite.

It is well known that the performance of conventional watches gradually deteriorates as the parts wear and as lubrication fails. For this reason watch manufacturers recommend periodic cleaning and re-oiling. In the ACCUTRON movement the gear train does not transmit torque, as does the train in a mainspring-powered watch. The pressure on pivots and jewels is negligible and the possibility of worn parts as the oil deteriorates is largely eliminated. Also, unlike conventional watches, lubrication and friction play no significant part in the timekeeping accuracy of the ACCUTRON movement, and there is no element that requires periodic adjustment to compensate for a progressive change. The above facts, confirmed by several years of field experience with the ACCUTRON timepiece, have caused BULOVA to recommend servicing only "as required," rather than periodically. Exceptions are, of course, annual replacement of the Power Cell and occasional regulation, if required.

No effort has been spared to make the repair of the ACCUTRON mechanism, when necessary, as simple as possible. Its repair draws upon skills possessed by any competent watchmaker—no knowledge of electronics being required. Before introducing this new product to the public in 1960, Bulova conducted numerous seminars for watchmakers throughout the United States to familiarize them with ACCUTRON. Since then, frequent lectures have been presented in the United States and in various other countries to provide service information to those interested in servicing the ACCUTRON timepiece. In addition, Bulova has widely distributed a detailed Service Manual. This Manual has been published in various languages.

The repair of ACCUTRON can be readily learned by the skilled watchmaker. He must, however, purchase certain specialized equipment. Many authorized Bulova ACCUTRON jewelers have equipped themselves to do this work. Others prefer to avail themselves of Bulova factory service where no effort is spared to repair, test, and return ACCUTRON timepieces within a few days of their receipt. Using air mail, the total time required for such factory service is comparable with that commonly experienced in local repair of conventional watches.

III the ACCUTRON *mechanism— how it operates*

the ACCUTRON *tuning fork*

The greatest difference between ACCUTRON timepieces and conventional watches lies in the use of a tuning fork in place of the balance wheel and hairspring as the time standard. The tuning fork has long been recognized as a *precision* frequency standard. Everyone is familiar with the tuning forks that are used as musical standards, such as the one illustrated in Fig. 8. Striking or twanging the fork makes it vibrate. The frequency of vibration, and hence the musical note that it gives out, depends upon the dimensions of the particular fork. The application of a tuning fork most familiar to the watchmaker is its use in the well-known Watchmaster Watch-rate Recorders. Here a tuning fork is the standard against which normal watches are checked for timekeeping accuracy.

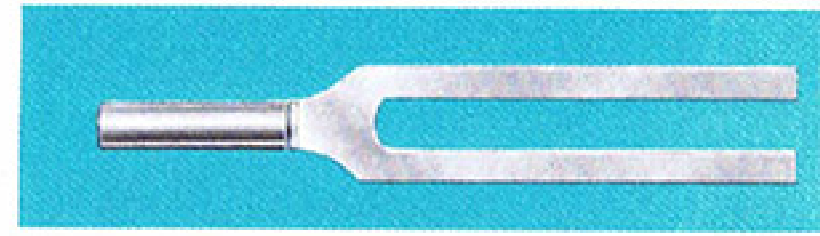


Fig. 8
Conventional Tuning Fork

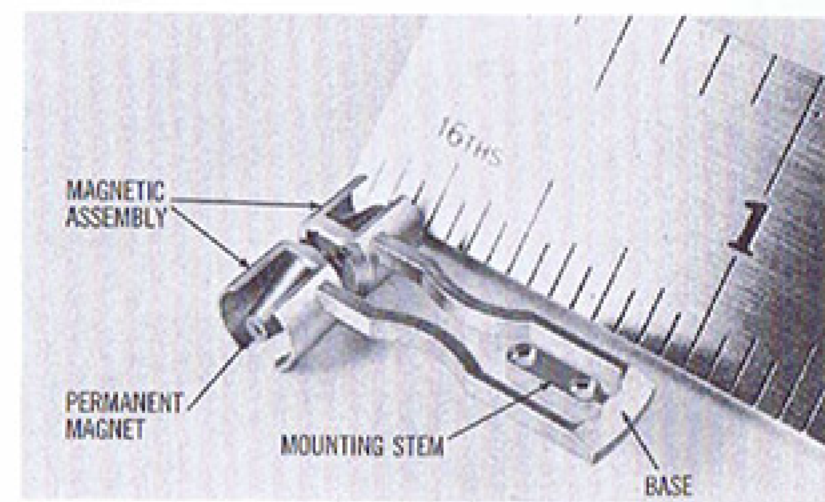


Fig. 9
ACCUTRON Tuning Fork

Fig. 9 shows the ACCUTRON tuning fork. The permanent magnet and surrounding magnetic cup on each tine are clearly visible. It is a relatively high-frequency device, vibrating 360 times per second in comparison with the 2.5 oscillation's per second of a typical balance wheel. Its accuracy is nearly independent of the position of the timepiece and of the habits of the

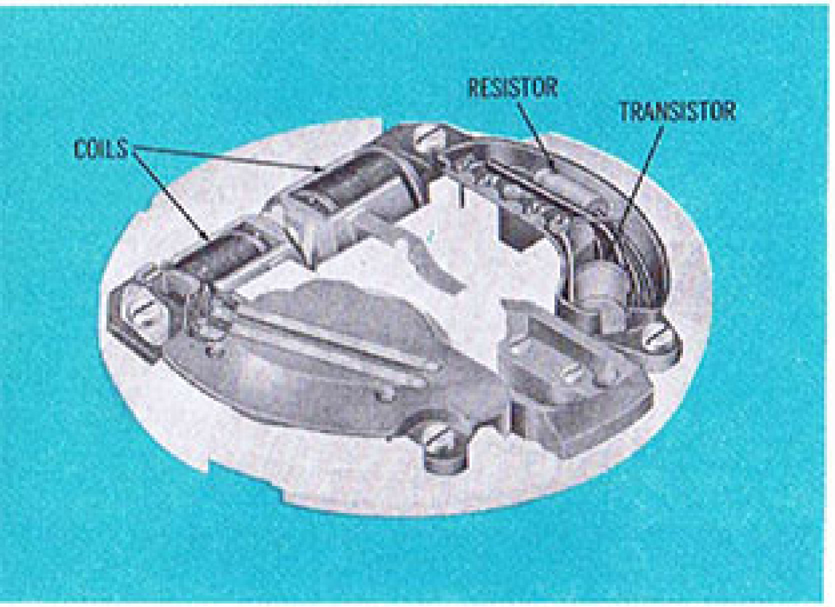


Fig. 10
Tuning Fork and Associated Circuit Elements (Front View)

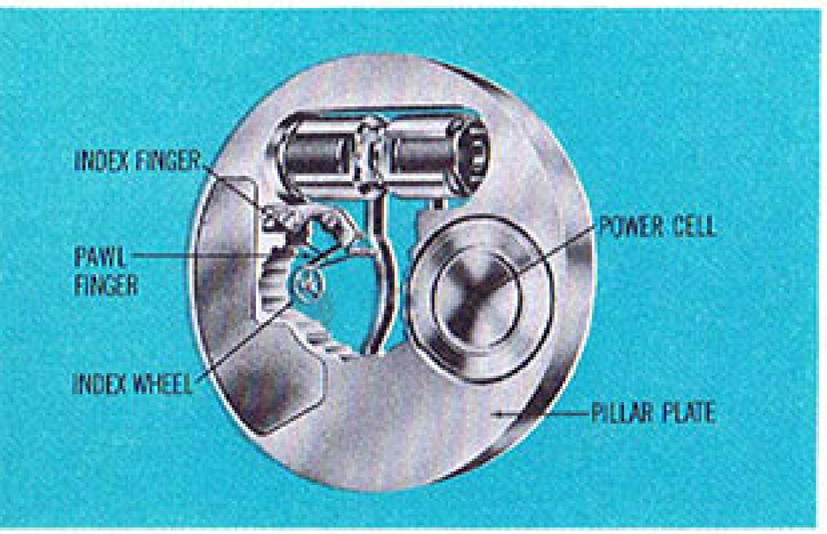


Fig. 11
ACCUTRON Indexing Mechanism (Rear View)

wearer. It is made from a self-compensating alloy similar to that used in watch hairsprings, so that its rate is comparatively unaffected by changes in temperature.

Fig. 10 shows the arrangement of the tuning fork with associated electronic circuit, as mounted on the pillar plate of the timepiece movement. The view shown is from the dial side. The tuning fork is caused to vibrate continuously by means of the electronic circuit which meters current pulses to drive the fork electromagnetically, energy being supplied by a self-contained power cell or battery, not visible in this picture. The tuning fork vibrates at its natural frequency, at a fixed amplitude established by the system parameters. The driving coils and all circuit elements and connections are mechanically attached to two complex plastic molded parts, clearly visible in Fig. 10. These two coil form assemblies are joined by wires (not shown) passing under the base of the tuning fork, and constitute a complete module which can be replaced in the field if circuit trouble is experienced, since field repair of the circuit elements is not practical.

vibratory-to-rotary motion conversion *the* ACCUTRON *indexing mechanism*

The vibratory motion of the tuning fork is converted into rotary motion, for turning the hands, by a ratchet and pawl system of simple construction. Fig. 11 shows the arrangement of the essential parts of the indexing mechanism, from the train (or rear) side of the movement. One tine of the tuning fork has attached to it a straight spring tipped with a tiny jewel which engages ratchet teeth on an "index wheel." It advances this wheel one tooth for each complete oscillation of the tuning fork. A pawl holds the index wheel in position during the return stroke of the index jewel. The pawl finger and jewel are similar to the index finger and jewel, except that the pawl finger is attached to the pillar plate of the movement. The shaft of the index wheel is provided with a pinion for turning the timepiece hands through a suitable train of gears.

Fig. 12 is a very much magnified drawing of the relationship between the index wheel and the two jewels that are in contact with it. Also indicated are the forces which exist in the system. As shown, the spring forces on the index and pawl jewels not only hold them in firm contact with the index wheel, but they also exert a torque on the wheel, which is always in the direction opposite to its forward motion. This is because of the geometry of the system and is not unlike the "draw" in a conventional escapement, which tends to hold the pallet fork against the banking pin. This tendency to "draw" the index wheel back against one of the jewels is very important to the reliable operation of the ACCUTRON indexing mechanism. In actual practice, each cycle of vibration of the tuning fork causes the index wheel to advance 1½ teeth beyond the initial position, then "draw" back ½ tooth for a net advance of exactly one tooth per cycle. Furthermore, the mechanism will tolerate a variation in tuning fork amplitude of about ±50% before improper indexing occurs. The following discussion will show how this is accomplished.

Fig. 13 is a diagrammatic representation of the sequence of events in the indexing mechanism, for three widely different amplitudes of vibration of the tuning fork. The mechanism is so constructed and adjusted that, when the tuning fork is at rest, with an index wheel tooth engaged by the pawl jewel (and held there by the "draw" effect described above), the index

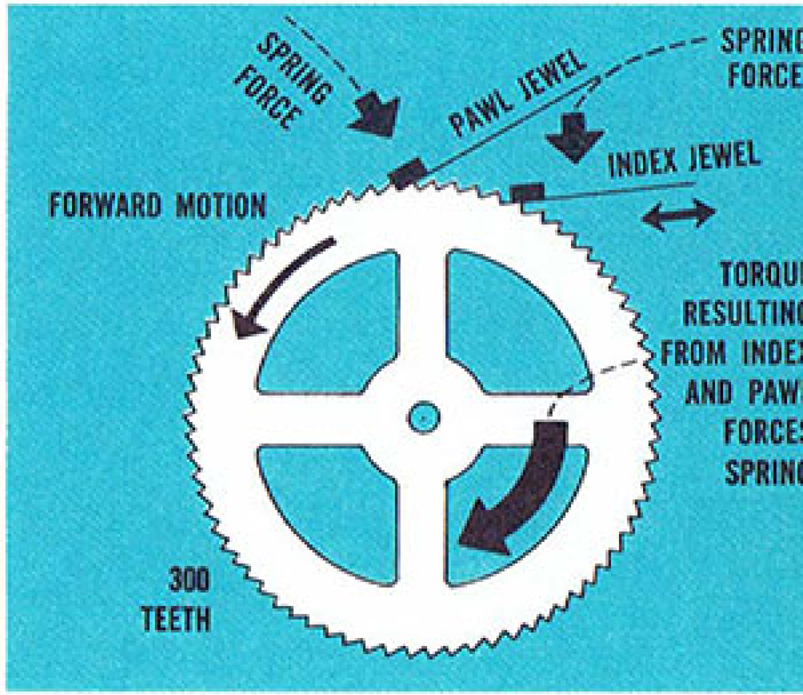


Fig. 12
Diagram of Indexing Mechanism

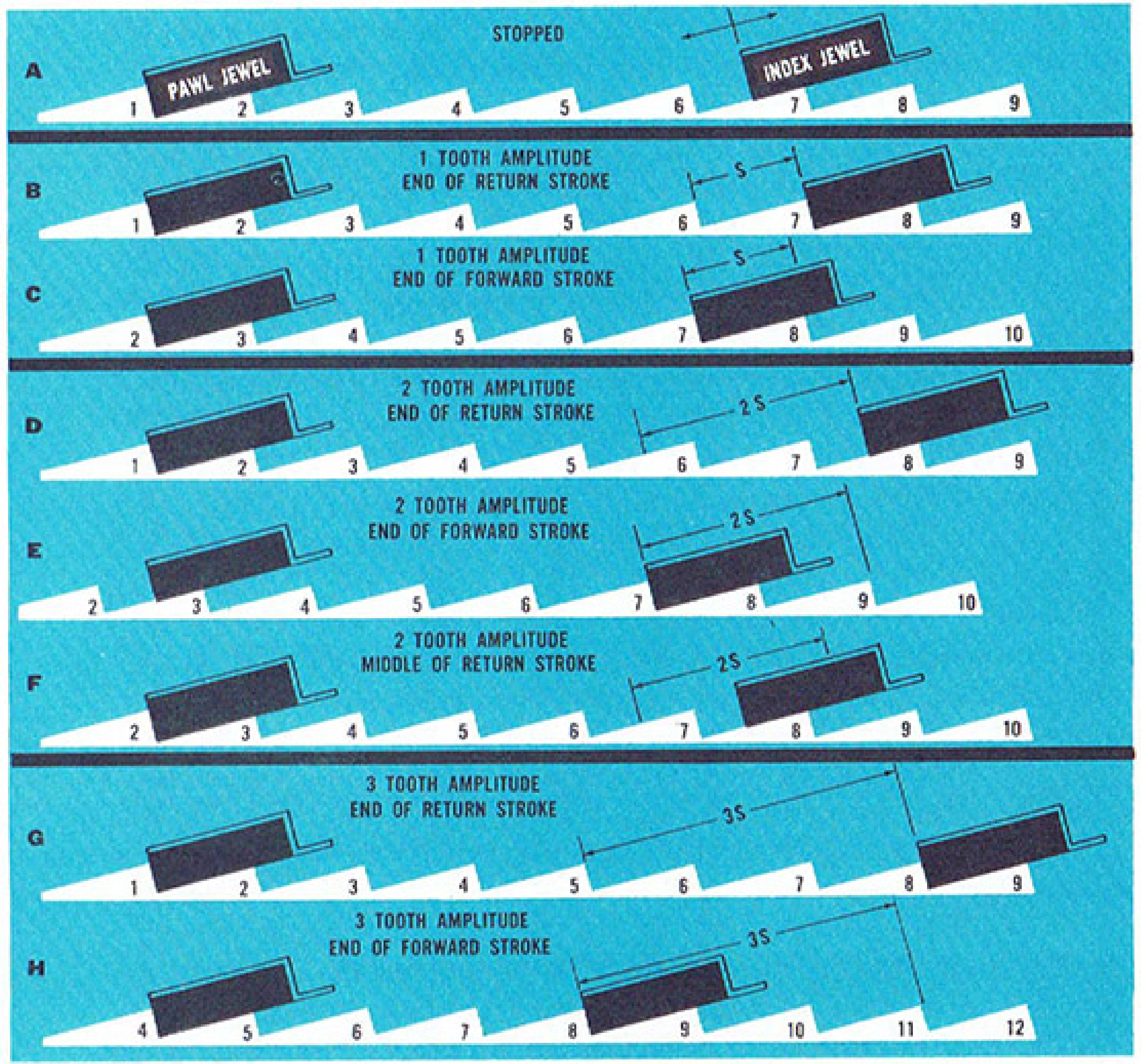


Fig. 13
Diagram of Indexing Mechanism Operation

jewel is located a number of teeth away in a position halfway between two teeth. For simplicity, the amplitude of travel of the index jewel is expressed in terms of tooth length (S). Fig. 13A shows the idle position, as described. Figs. 13B and 13C show a complete cycle of oscillation at an amplitude of one tooth (½ tooth right to ½ tooth left of the rest position). In moving to the right ½ tooth, the index jewel picks up tooth No. 7, and on its return stroke to the left it drives the wheel far enough for the pawl jewel to drop off the end of tooth No. 2, so that the wheel is advanced one tooth. Further oscillations at the one-tooth level of amplitude would advance the wheel exactly one tooth per cycle.

Figs. 13D-13F indicate the sequence of events at an amplitude of two teeth (one tooth to the left and one tooth to the right of the rest position). The index jewel, in going one tooth to the right, drops off tooth No. 7, and goes halfway along tooth No. 8. On the forward stroke, however, the first half tooth of travel accomplishes no movement of the index wheel, since the index jewel does not begin to drive the wheel until it strikes tooth No. 7. In Fig. 13E, tooth No. 2 has passed beyond the pawl jewel; but after the start of the return stroke the "draw" effect exerts torque on the wheel to bring it back ½ tooth to the position shown in Fig. 13F. Thus, with a two-tooth amplitude of travel of the index jewel, one-tooth rotation of the index wheel results per cycle of oscillation of the tuning fork.

Figs. 13G and 13H show the effect of a three-tooth amplitude. The index jewel, in going to the right 1½ teeth, picks up tooth No. 8. At the other end of the stroke, it has moved tooth No. 8 into the position where tooth No. 5 was. The pawl jewel has dropped off the end of tooth No. 4, resulting in a three-tooth advance of the index wheel.

It can be seen that, for any amplitude from just over one tooth to just under three teeth, the index wheel advances one tooth for each vibration of the tuning fork. When the total travel of the index jewel reaches three teeth on the index wheel, this wheel advances more than one tooth for each tuning fork vibration; in fact, it advances three teeth, and under conditions where the tuning fork reached such an amplitude the hands would advance at three times their proper rate.

The amplitude of vibration of the tuning fork is controlled at such a value that the index jewel travel is about two teeth. From the above discussion it is apparent that the indexing mechanism will tolerate about ±50% variations in tuning fork amplitude from this nominal value before the timepiece hands fail to advance in exact synchronism with the vibrations of the tuning fork. The indexing mechanism therefore permits wide variations in tuning fork amplitude to occur, with no effect upon the proper functioning of the timepiece.

One of the less obvious but nevertheless very important requirements of the indexing mechanism to permit it to function as described is that which assures that the relative position of the two jewels is exactly as shown in Fig. 13. Maintaining an exact number of index wheel teeth between the two jewels is not necessary. However, the index jewel must rest in the *middle* of a tooth in the idle condition as shown in Fig. 13A. The design of the movement provides a vernier adjustment to establish this condition during repair.

It must be realized that the diagrams are greatly magnified. Actually, the ACCUTRON index wheel is only 95/1000 of an inch in diameter; it contains 300 teeth. These teeth are extremely small. A human hair would be

1 inch in diameter at the same scale used in Fig. 13, and would span three index wheel teeth. However, in spite of these small dimensions, the mechanism functions exactly as described and experience has shown that this entire system is completely reliable. The fact that the ratchet system is small does not alter in any way the physical principles involved in its operation.

the ACCUTRON *electromagnetic tuning fork driving elements*

Before discussing the electronic circuit it is necessary to explain the interrelation of the magnets on the tuning fork tines and the coils of wire connected to the electronic circuit. Referring to Fig. 14 the cup-like part attached to each tuning fork tine is made of iron, as it must be magnetic. Mounted in the center of each of these cups is a conical magnet. Between each cup and its central magnet is a strong magnetic field. The coils of wire wound on the plastic forms extend into the space between the respective magnets and cups, and these coils therefore lie within the magnetic field, without touching the moving parts attached to the tuning fork. These coils are supported by the pillar plate.

If a current is passed through one of these coils of wire, this coil becomes an electromagnet. It will then either attract or repel the associated magnet-and-cup assembly, depending upon the relative magnetic polarities. Conversely, if a magnet-and-cup assembly is moved within its associated coil, a voltage is induced in this coil, the polarity depending upon the direction in which the magnet assembly is moved. As the tuning fork vibrates, an

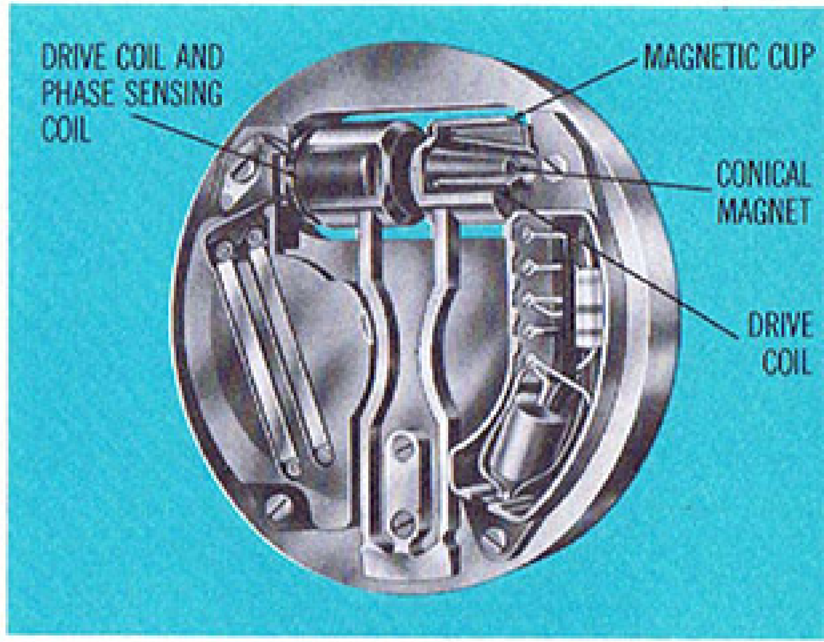


Fig. 14
Cutaway View of
ACCUTRON Electro-magnetic Elements

alternating voltage is constantly induced in the two coils. This voltage is a direct measure of the amplitude of vibration of the tuning fork. It is this induced voltage which permits the circuit to sense and control the amplitude of vibration.

One other feature of the arrangement of the electromagnetic parts, which can be observed in Fig. 14, is that there are four wires leading from the coil on the left. This coil is in two sections, with one end of each section connected together. The result is that while most of the turns of wire on the left-hand coil are used to drive the tuning fork, approximately one quarter are used to form what is termed the "Phase Sensing Coil." It is this coil which determines the proper instant in each cycle at which the pulse of current is applied to the driving coils, to maintain the oscillations of the tuning fork.

The electromagnetic system, therefore, serves a triple purpose:

1. To convert pulses of electric current into mechanical impulses which drive the tuning fork.

2. To provide the means by which the electronic circuit may sense the tuning fork amplitude.

3. To control the instant in each tuning fork cycle during which the driving current pulse is delivered.

The following paragraphs describe the manner in which the electronic circuit, in combination with the electromagnetic tuning fork driving elements, combine to control the tuning fork amplitude at the prescribed value for optimum functioning of the mechanical indexing mechanism.

the ACCUTRON *electronic circuit*

Fig. 15 is a schematic diagram that shows the connections in the ACCUTRON electronic circuit. The transistor in this application may be thought of as a relay, although it is an electronic device without moving parts or contacts. In a relay, a small current through the coil operates electrical contacts that can switch a much larger current.

A transistor has three terminals: the emitter, base and collector—indicated on the schematic by the letters E, B and C. The base-to-emitter leads must be supplied with current to cause the emitter-to-collector circuit to conduct. In other words, the collector circuit is conducting only when there is current in the base circuit of the transistor. The current through the base-to-emitter terminals of the transistor, in this application, may be compared with the coil current of a relay; the current through the collector-to-emitter terminals may be compared with the current that is switched by the relay contacts. The advantages of a transistor over a relay are the transistor's extremely small size, its ability to operate with minute currents, and the complete absence of moving parts.

The capacitor, shown on the left in Fig. 15 with a resistor connected in parallel with it, is the element which maintains the transistor in a non-conducting condition through most of each cycle of operatic of the tuning fork. As explained previously, an alternating voltage is luced in the

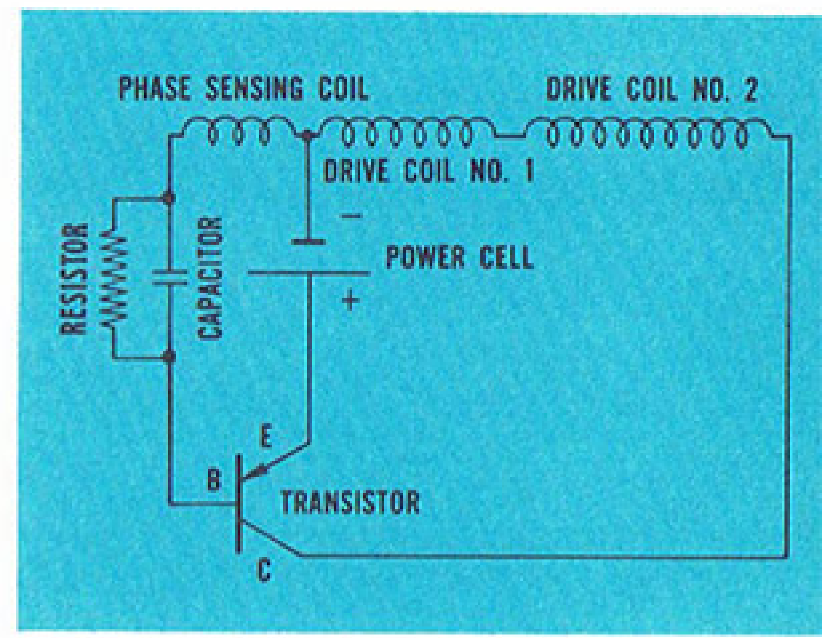


Fig. 15
Schematic Diagram of ACCUTRON Circuit

phase sensing coil by the vibrations of the magnet associated with it. Through the base circuit of the transistor, which acts as a diode or rectifier, this voltage is added to the Power Cell voltage to charge the capacitor, which functions as a storage tank for electricity. The resistor across this capacitor causes a slight "leak," with the result that the capacitor will be re-charged slightly, once each cycle, by the peaks of the alternating voltage induced in the phase sensing coil. It is these re-charging pulses of current which cause the transistor to conduct momentarily and allow current to flow in the driving coils to pulse the tuning fork and maintain its vibrations.

Fig. 15 shows that the drive coils are connected in series with the Power Cell and the transistor's collector and emitter terminals. The transistor is caused to conduct at the point where the voltages induced in the phase sensing and drive coils are about at their maximum instantaneous values, and when the drive coil induced voltage is opposite in sign to the Power Cell voltage. Therefore, if the amplitude of the tuning fork should be such that at the instant the transistor becomes conducting the induced voltage in the drive coils exactly equals the Power Cell voltage, no current would flow, since the two voltages are opposite in polarity, and would cancel each other.

The key to the operation of the amplitude control system is the design of the magnet and coil system, so that at the proper amplitude of vibration for the tuning fork, the voltage induced in the drive coils has a peak value about 10% less than Power Cell voltage. Because of this, a 10% *increase* in amplitude, resulting from a disturbance, would cause the driving current pulses to be reduced to zero and the tuning fork would rapidly return to its proper amplitude. Furthermore, a 10% *decrease* in amplitude of the tuning fork would cause the driving current pulses to double and again return the tuning fork very rapidly to the proper amplitude.

In principle, it has been shown that the tuning fork amplitude is controlled by converting it into a voltage, which is maintained at a value about 10% below Power Cell voltage. The Power Cell is designed to provide a very constant voltage for approximately 99% of its useful life; hence the tuning fork amplitude remains at its proper value or returns to this value within a very small period of time after any disturbance. It is the inter-relation between the indexing mechanism, the coil and magnet elements, the Power Cell, and the electronic circuit which results in the accurate, reliable operation of ACCUTRON timepieces.

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Bienne, Switzerland

Neuchatel, Switzerland