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ULTRASONIC METHOD OF LUBRICATING A COMPLEX MECHANISM

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This invention relates to an ultrasonic method of coating complex assemblies for purposes of protection, insulation or friction reduction, without the necessity of disassembly to reach and individually coat blind holes, recesses, and other relatively inaccessible places therein. In particular, the invention relates to such a method having special utility for the lubrication of delicate mechanisms such as watch movements and the like.

As in the case of other machines, a watch movement requires periodic overhauling and lubrication. Overhauling is normally considered synonymous with cleaning which generally includes washing the involved parts to remove oxidized oil and foreign matter, such as lint, dust, etc., therefrom. Oxidized oil is dry and gummy and hence a prime source of watch malfunctioning and small particles of foreign matter can easily clog the tiny teeth on the working gears, as well as other working parts, of a watch movement and cause it to run poorly or even stop completely. Moreover, where, as is always the case, oxidized oil and foreign matter are both present in a watch movement, the operation of its mainspring is hindered to a greater and greater extent by the consequent resistance until, assuming the condition remains uncorrected, it ceases to function completely. Conventionally, when a watch is in need of cleaning, its movement is dismantled and each part washed, dried, and lubricated as needed, after which the movement is reassembled. Experience has proven that the interval from the time a watch is cleaned and lubricated to the time when it is again in need of such servicing is normally from about nine to about eighteen months, depending of course, upon environmental conditions.

In recent years, ultrasonic methods of cleaing watches and other precision parts and assemblies have become more and more common. There are several inherent advantages in the use of ultrasonic cleaning, a principal one of which is the ability to thereby effect the cleaning of a precision assembly intact, that is, without the necessity of the otherwise requisite disassembly and reassembly steps. This is important not only because of its obvious time, effort and money saving consequences but also because it avoids the contamination that inevitably occurs to some extent during any assembly or reassembly operation. The latter benefit is of prime importance to watchmakers since their work is usually performed in places exposed to much airborne contamination.

However, while, as indicated, ultrasonic cleaning alleviates part of the watchmaker's burden, one major difficulty attends its use. Thus, though a watch movement can be cleaned ultrasonically in fully assembled form, there still remains the age-old problem of getting proper amounts of fresh lubricant into its various internal recesses, some of an extremely minute character, in need of oiling. Heretofore, the only known method for successfully accomplishing this has been disassembly of the cleaned watch movement and subsequent hand oiling of the then-exposed critical points requiring lubrication. Conventionally, such hand oiling is accomplished with the aid of oil applicators or, as they are sometimes called, oilers.

Oilers of one type are bits of hair-thin wire, made in varying thicknesses, whose ends are flattened slightly to permit a tiny bead of oil to cling thereto when dipped into an oil cup (an oil container used by watchmakers).

When the flattened tip of an oiler carrying such a bead of oil is applied to a part of a watch movement in need of lubrication, typically a pivot in a bearing hole, the oil is transferred from the oiler to the part in question. Another type of oiler, now coming into prominent usage, is in the shape of a pipette with its hollow member fashioned from small capillary tubing. The application of the proper amount of oil is of the utmost importance, this being one of the most demanding of the watchmaker's chores. The addition of too much oil can cause as much trouble as, and possibly more than, the addition of an insufficient amount.

Among the most critical and difficult parts of a watch movement to oil are its capped jewels. Capped jewels, as those skilled in watchmaking are aware, are the jeweled bearings supporting the ends of watch balance staffs. A capped jewel comprises a cap jewel against which one end of a balance staff abuts and a cooperating hole jewel through which the staff pivot protrudes in bearing relationship therewith. The cap and hole jewels are fixedly secured in settings appropriately located to maintain them in properly spaced apart relationship with roughly parallel facing sides.

The oiling of a capped jewel is accomplished by placing a small globule of oil in the opening in the hole jewel and then forcing the oil through that opening and onto the adjacent cap jewel with a fine pointed wire having a diameter substantially smaller than that of said opening. Capillary action draws the oil into the space between the cap and hole jewels to form a small flat bubble between their facing sides. The size of the bubble is adjusted by the addition of oil as needed until its spread diameter is larger than that of the opening in the hole jewel but preferably not greater than about two-thirds that of the cap jewel. It is important to here employ a proper amount of oil to assure functioning of the involved watch for its normal trouble-free period of operation between cleanings. Too much oil is deleterious in that it floods the hole jewel openings, normally referred to by watchmakers as cups. During and after oiling, it is essential that the watchmaker closely observe the size of the oil bubble between the cap and hole jewels with his eye loupe to make sure that the oil is present in the desired amount and has not spread or spilled away. It will be apparent from the foregoing that the proper oiling of capped jewels is a time consuming procedure and that it requires the skilled eye and trained hand of an experienced watchmaker, both of which (time consumption and the need of a skilled craftsman) make for high expense to the customer.

Other minute recesses in the watch mechanism requiring oiling occur in the train jewels. The hand oiling of such jewels is accomplished by applying the oil bearing tip of an oiler to the appropriate pivot at the point of its emergence from the bearing hole in a train jewel. When this technique is employed, capillary action pulls the oil and keeps it properly distributed around the pivot in its jewel bearing hole. There are, of course, other minute areas and recesses in a watch movement which require oiling and are difficult of access, but those described are adequately illustrative of such hard-to-reach spots or, as they are sometimes called, crevices.

We have now discovered an ultrasonic vibration method of oiling complex assemblies by means of which all of the above-noted, and other, minute crevices in watch movements can be reached with a liquid lubricant in the proper amount, without having to first go through a disassembly step. We have further discovered that, in addition to being able to reach such minute hidden recesses with a lubricating liquid, we can, by a technique hereinafter disclosed, effect optimum distribution of the lubricant throughout the inner workings of delicate mechanisms.

This is of significant importance to watchmakers and others of similar skills since, as is well known, watch movements and the like have some parts requiring more lubrication than others and some parts which must, for optimum functioning capability, be entirely free of lubricant.

It is thus a principal object of this invention to provide a method whereby the innermost bearing recesses of a watch movement or the like can be lubricated simply and quickly with proper amounts of lubricant and without the necessity of a prior disassembly step.

It is another object of the invention to provide a method for accomplishing effective distribution of lubricant throughout a watch movement, or equivalent mechanism, in its assembled form.

Other objects, features and advantages of the invention will become apparent as the description thereof proceeds.

Consistent with the first of the above-stated objects, we achieve lubrication in the innermost and least accessible recesses of a delicate mechanism such as a watch movement by immersing it in a solution of a suitable lubricant in a relatively volatile solvent while concurrently subjecting both mechanism and solution to ultrasonic energy vibrations. The procedural details, concentration of lubricant in solvent, ultrasonic energy requirements, etc., of this "sonication" treatment will be described in greater detail below. Suffice it to say here that as a result of the sonication treatment the lubricant solution is rapidly forced into the least accessible recesses in the mechanism. Immersion alone, unaccompanied by the ultrasonic vibration, or sonication, does not accomplish this result since the lubricant solution, because of its surface tension characteristics, flows only slowly, if at all, into the more minute recesses or crevices of said mechanism. Thus, it might take hours, or even days, to get complete saturation of the mechanism with the solution, and it is not at all certain that such would ever, in fact, be achieved.

We believe that the reason why the above-indicated immersion without sonication procedure does not accomplish our purpose is because the relatively high surface tension of the lubricant solution results in the formation of small air pockets within the immersed mechanism and that these air pockets tend to become lodged in narrow passages and thereby prevent complete circulation of the lubricant solution through all interstices of the mechanism. The introduction of ultrasonic energy into the solution, however, literally tears the liquid apart and, we think, prevents the existence of surface tension films around air pockets and, hence, the existence of the pockets themselves. In any event, we have found that the introduction of ultrasonic sound energy into such a lubricant solution causes it to flow into all critical recesses of an immersed watch movement in a matter of a very few minutes, three to four minutes being completely satisfactory in most cases. Hereinafter, for the sake of simplicity, those assemblies amenable to treatment by the method of this invention will be referred to in the generic sense simply as mechanisms, without repetitive qualifications.

The above-denoted sonication treatment is merely the first step of our process in its preferred form. The next step of the process comprises withdrawal of the sonicated mechanism from the lubricant solution and subjection of it to drying treatment in a stream of air, or otherwise, to effect rapid evaporation of the volatile solvent from the solution adhering thereto and leave a coating or deposit of lubricant behind. The sonication and drying steps so far described result in the deposition of lubricant in the hard to reach inner recesses of the involved mechanism, perhaps the most important accomplishment of our method. However, the sonication and drying steps normally accomplish too much in that they succeed in not only depositing lubricant in the difficultly accessible areas within such a mechanism but also on all of its surfaces of contact with the lubricant solution. This is good insofar as

those surfaces requiring the presence of substantially the amount of lubricant deposited are concerned. However, many such surfaces require less than this amount and some, such as the balance wheel or hairspring surfaces in watch movements, must be entirely free of lubricant for most effective operation of the mechanism. Thus, momentarily concentrating upon watch movements for the sake of emphasis, our sonication and drying steps yield a watch superbly oiled at its innermost and least accessible bearing points but overoiled at various other places, some of which should, for optimum or even acceptable operation of the watch, be entirely oil free. It is perhaps appropriate to point out that the terms "oil" and "lubricant" are not entirely synonymous, the former being the broader of the two in that it includes liquids intended to form protective surface coatings as well as those intended only for friction reducing purposes. Both oils and lubricants are applicable by means of our process and hence fall within the functional scope of our invention.

We have discovered that excess lubricant can be removed in precisely the right proportions from the various surfaces of accumulation within a mechanism sonicated and dried as taught herein, by dipping the mechanism into a suitable solvent for a relatively short period of time. Manipulative technique plays an important part in the dipping procedure and pertinent details will subsequently be disclosed. It can presently be said, however, that by a judicious combination of suitable solvent, optimum immersion time or times, undersolvent manipulation of the mechanism, etc., a dipping procedure excellently effective for the removal of lubricant to the desired extent from each surface within said mechanism needful of such removal while leaving those previously-indicated bearing, and other, points which are difficultly accessible of reach and require the presence of lubricant virtually unaffected, thus yielding a superbly lubricated mechanism. The instant dipping procedure is unaccompanied by sonication since, as we have discovered, such sonication renders the procedure too effective in that it results in the removal of lubricant from all parts of the watch movement rather than only those parts readily exposed to the solvent. The solvent here employed may or may not be the same as that utilized for the preparation of our lubricant solution.

As we have previously indicated, the ultrasonic cleaning of watch movements is known. In this connection, it is feasible, and even preferred in most instances, to combine our ultrasonic lubricating process with a precedent ultrasonic cleaning step whereby both cleaning and oiling of a watch can be accomplished without ever having to disassemble it. There are various ways of ultrasonically cleaning watch movements known to those skilled in the art, and various devices are commercially available for carrying out ultrasonic cleaning techniques. Exemplary of the latter is the Watchmaster Ultrasonic Cleaner, a four-cup watch cleaning unit made and distributed by Watchmaster Products, Inc., Division of Bulova Watch Company, of Woodside, N.Y. The Watchmaster unit, hereinafter referred to simply as the ultrasonic cleaner, can be adapted for use in our ultrasonic lubrication process and hence will now be described in some detail.

The ultrasonic cleaner is, as previously indicated, a four-cup unit, three of the cups being so adapted as to each contain either a washing or rinsing solution, and the fourth being a so-called spin-dry cup in which washed and rinsed watch movements are rapidly spun in a stream of warm air until dried of rinse solution. Since the construction and method of operation of the ultrasonic cleaner are well known, it is not necessary to discuss those details here. Suffice it to say, that the four cups of the ultrasonic cleaner are supported in stepwise arrangement, two on a lower level and the remaining two on a higher level. The two lower level cups are known as the wash and ultrasonic rinse cups and the other two as the hand-rinse and spin-dry cups, respectively.

The ultrasonic cleaner has a box-like framework, stepped on its upper side, with four receptive openings into which the aforesaid cups respectively fit. In addition to the above-named parts, the ultrasonic cleaner has two transducer units respectively disposed beneath the two lower (wash and ultrasonic rinse) cups and so mounted as to impart ultrasonic energy to the contents of either cup upon appropriate activation by a timer switch arrangement built into the cleaner. Also, the ultrasonic cleaner has an accessory wire mesh basket and cooperating thimbles into which the parts of the watch movement to be ultrasonically cleaned are placed, the basket being so designed as to slip easily into any of the four cups (all incidentally, being of the same size) for use throughout the various stages of the watch cleaning operation.

In one method of cleaning a watch in the ultrasonic cleaner, its movement is placed in an appropriate slot in the aforesaid basket, and certain of its small parts, which have been removed for the purpose, are placed in a thimble which is likewise placed in the basket. The basket is designed to hold as many as six watch movements, and the interrelated parts normally cleaned concurrently therewith (the "small parts" above referred to), thus making it possible to clean that many watches all at the same time.

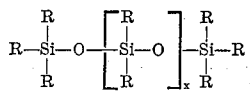
The watch-laden basket is placed in the ultrasonic wash cup which has previously been filled to a level about ⅛ to about ¼ inch above the top of the fully inserted basket wth a suitable watch cleaning solution. The wash cup transducer is activated and operated for three minutes after which the basket is removed from the wash cup and dipped into the hand-rinse cup containing a suitable rinsing solution. Next, the basket is transferred to the ultrasonic rinse cup containing a suitable rinsing solution to about the level of the watch cleaning solution in the wash cup and sonicated therein for 2½ minutes. The just-described rinse sonication step is repeated in another cup of rinsing solution. Finally, the basket is transferred to the spin-dry cup (which has been preheated in accordance with a prescribed procedure) and spun therein in a transverse rotary motion for about 6 minutes.

The various types of wash and rinse solutions suitable for watch cleaning purposes are known to those skilled in the art and need not be discussed in detail here. The subject cleaning procedure has been described in a certain amount of detail primarily as a foundation for a more thorough understanding of our hereinafter described ultrasonic watch oiling procedure, the latter being performed in the ultrasonic cleaner in accordance with a technique similar to the cleaning technique in some respects but otherwise at variance therewith.

The preferred lubricants for purposes of this invention are selected from the silicones, the silicones being polymerization products of compounds having the general formula



in which R is an alkyl, substituted alkyl, aryl or substituted aryl radical and R′ is an alkyl, substituted alkyl, aryl or substituted aryl radical. An example of one such polymerization product is that having the general formula



in which each of the R radicals is an alkyl, substituted alkyl, aryl or substituted aryl radical and x represents any integer. In the foregoing formula, the R radicals may be alike or different.

We prefer the silicones to commercial watch oils as lubricants for several reasons, chief among which are the fact that silicones are more resistant to oxidation than are such oils and the fact that the latter are solutions of hydrocarbon lubricants and various additive ingredients which may, after dilution with a solvent and subsequent solvent removal as required by our process, dissociate into their component parts, thereby losing, to a greater or lesser extent, their property of lubricity, and perhaps other of their critical properties. While, as indicated, we prefer the silicones for our purpose, the present invention is not so limited and hydrocarbon, or other suitable, lubricants can be employed in their stead if desired.

Any silicone, or mixture of silicones, will be effective, at least to some extent, for the lubricating purposes of this invention. For example, the simple unsubstituted silicones, such as dimethyl silicone, methyl phenyl silicone, etc., are effective since they have ideal thermal and oxidative stabilities as well as chemical hydrolytic stability, and they are within operative viscosity and shear stability ranges. It has been determined, however, that these unsubstituted silicones are somewhat deficient in an ability to lubricate under boundary conditions, boundary conditions being those obtaining when a lubricant film between sliding surfaces of contact becomes extremely thin thus creating a danger of actual contact therebetween at microscopic high points, technically known as asperities, present on all such surfaces. Boundary lubrication is of greatest significance when there is bearing contact between two metal surfaces but we have found that silicone lubricants known to have superior lubricating characteristics under boundary conditions are, interestingly enough, preferred lubricants for use in our lubricating method. This seems a coincidental, rather than a correlative, circumstance since our method has primary utility, insofar as now contemplated, for the lubrication of watches and watch bearings are, in most instances, jewels, thus precluding the possibility of metal-to-metal frictional contact within watch movements. Some watches, however, have metal bearings and here it is not difficult to find correlation rather than coincidence in the described circumstances.

To lubricate effectively under boundary lubrication conditions, a lubricant must have the ability to adhere to metal surfaces, either through physical adsorption or chemical reaction. The desired layer of lubricant, a few molecules thick, on a metal surface subjected to boundary lubrication conditions is achieved either by the inherent chemical nature of the lubricant employed, or by the presence of extreme pressure additives which are chemically active. Ideally, under boundary conditions, high spots on the opposing metal surfaces are separated by thin molecular layers of lubricant (or additive) adhering to each surface. It has been found that certain commercially available methyl chlorophenyl silicone lubricants are optimumly effective under true boundary lubrication conditions. The presence of chlorine in these lubricants, as part of the silicone molecule, is believed to provide the chemical reactivity with metal surfaces necessary for effective boundary lubrication.

Consistent to what has already been said on the subject, the commercially available methyl chlorophenyl silicones are excellent lubricants for purposes of this invention. Examples of commercially available lubricants of this class are the Versilube fluids (alternatively referred to as Versilube lubricants, Versilube silicone fluids or Versilube silicone lubricants), the trade designation "Versilube" being a registered trademark of General Electric. Of the available Versilube fluids, we prefer one designated as Versilube F–44 for our purpose, Versilube F–44 being methyl tetrachlorophenyl silicone coupled with an oxidation inhibitor.

Our preferred silicones are those with viscosities from about 25 to about 200 centistokes, Versilube F–44 having a viscosity of 75 centistokes at 77° F. The individual Versilube silicone fluids, as is also true of other commercially available silicones, are not separate chemical

compounds but mixtures of polymers of varying molecular weights. For example, Versilube F–50, a silicone fluid without an oxidation inhibitor but otherwise the same chemically as Versilube F–44, is composed of polymer molecules varying in molecular weight from 800 to 6,000, about half being between 2,500 and 3,500 in molecular weight. In addition to the Versilube fluids, there are other commercially available silicone products well suited for purposes of this invention, an example of one such being Dow Corning 560 Fluid, a chlorophenyl silicone lubricant manufactured and sold by Dow Corning Corporation of Midland, Mich.

The class of suitable solvents for use in our process is large and, in fact, any solvent will suffice, at least to some extent, so long as it is more volatile than the involved lubricant. However, the more rapidly the solvent evaporates the more effectively will it perform its function. The reasons for this are several, chief among which are: (1) the obvious edge in efficiency attributable to faster accomplishment of the desired result; (2) an increased ability of the solvent to escape from the hard-to-reach inner recesses of the sonicated mechanism while leaving substantially all of the dissolved lubricant behind (a slow drying solvent allows more time for the lubricant-solvent solution to flow back out of the recesses thereby resulting in less retention of the lubricant); and (3) the greater assurance which a relatively fast drying solvent offers of separation of substantially all of the solvent from the lubricant (unvaporized, or residual, solvent in the lubricant thins it and has a deleterious effect on its lubricity).

While it is generally true, as indicated, that the faster drying solvents are preferable to slower drying ones for our purpose, such is not always the case. Thus, under the conditions of relatively high humidity known to prevail in certain parts of the world, there are exceptions to this generality. Such exceptions obtain with respect to solvents sufficiently fast drying to cause moisture condensation on affected watch movement, or equivalent, parts caused by the rapid extraction of heat therefrom and consequent cooling of their surfaces below the dew point of the surrounding atmosphere. Common sense dictates that under environmental conditions conducive to such moisture condensation, the selection of a suitable solvent for our process will sometimes favor less volatile over more volatile materials. Under these circumstances, it is, of course, possible to prepare tailor-made solvent solutions of desired drying rates by mixing solvents of appropriate drying times and other suitable properties.

As will be apparent from the foregoing, the solvents of this invention are suitably of organic character. Of the numerous classes of materials within this category, and subject to the above-specified qualifications, the so-called halogenated solvents are generally preferred because of their relatively high volatilities and inertness by comparison with other organic solvents. Exemplary of the here-contemplated halogenated solvents are 1,1,1 - trichloroethane, ethylene dichloride, methylene chloride, perchloroethylene, trichloroethylene, the Freons (trademark designation for a group of hydrocarbons containing one or more fluorine radicals which are widely used as refrigerants and propellants), etc. While, as indicated, we prefer to use halogenated solvents in the process of our invention, the invention is not limited thereto and many other organic solvents can be employed within its scope. For example, alcohols such as methanol, ethanol, isopropyl alcohol, etc.; esters such as ethyl acetate, etc.; ketones such as acetone, ethyl butyl ketone, etc.; aliphatic petroleum naphthas such as Stoddard solvent, varnish makers' and painters' naphtha, etc.; and aromatic solvents such as xylol, etc., are suitable solvents for use in our invention.

As is believed apparent from the above discussion, there is no easily defined class of solvents to which this invention can be legitimately limited. Suffice it to repeat, that the basic requirement of a solvent suitable for our purpose is that it evaporate faster than its cooperating lubricant, subject to the previously indicated qualifications with respect to highly volatile solvents in humid atmospheres. To the foregoing may be added the precautionary provision that the solvent be substantially inert with respect to said lubricant, as well as to those objects it must contact in use. Finally, it is preferable (although not essential) that the chosen lubricant be soluble, or substantially so, in the subject solvent.

While for reasons indicated we do not wish to pin our class of suitable solvents down to a specific range of volatilities, it is convenient to characterize a preferred category of such solvents by their drying times. The term "drying time," as employed by solvent chemists and others familiar with solvent chemistry has a specialized meaning, this being the time required for one drop of a liquid to completely evaporate from a porous material under standardized conditions of temperature and pressure. Drying time values are, as will be apparent, connotative of liquid volatilities. The apparatus used for drying time determinations, and the test conditions (pressure and temperature) observed for such procedures, are sufficiently standardized throughout the solvent industry, and wherever such techniques are elsewhere employed, to thereby provide a useful tool for determining the relative volatlities of liquids. In view of this standardization of technique and equipment, and common knowledge thereof among those skilled in the art, no necessity is seen for a more detailed discussion of drying times or their method of determination here.

In illustration of the efficacy of drying time determinations as a tool for liquid volatility comparisons, it can be noted that the preferred solvent for our purpose (which we have discovered to be 1,1,1-trichloroethane, one of the above-named halogenated solvents) has a drying time of 1.0 minute whereas xylene, a common solvent normally considered to have a fairly high rate of evaporation, has a drying time of 10.8 minutes indicating that it evaporates at only about one tenth the rate of the 1,1,1-trichloroethane. Subject to all qualifications and limitations heretofore indicated, the preferred solvents for use in our invention are those having drying times of from about half a minute to about five minutes. Of the various liquids within this drying time range, the halogenated solvents as previously indicated, are felt to be most effective for our purpose.

The concentration of lubricant in our lubricant-solvent solution is a significant factor in the practice of our invention but it is difficult to pin down a preferred range of concentrations since the effect of solution strength depends upon the particular lubricants and solvents employed and, to some extent, upon the particular mechanism on which the solution is to be used. In general, however, solutions of relatively low lubricant concentration, such as those containing from about 0.1 to about 45 percent by volume of lubricant, are preferred for our purpose. If the lubricant concentration falls below this range, subsequent lubrication of a watch movement with the solution is generally inadequate whereas if it exceeds the range such lubrication may result in over-oiling of the movement. Where our preferred lubricant solution ingredients (Versilube F–44 silicone fluid and 1,1,1-trichloroethane solvent) are employed, we have discovered a lubricant concentration of about 2% by volume to be optimumly effective for use in the oiling of most conventional wrist watch movements. The preferred range of lubricant concentrations for solutions of the named ingredients is that from about 0.5 to about 5 percent by volume. It will be apparent, however, that our method is not necessarily limited to the use of this range in view of the many possible ingredient combinations and oiling applications within the scope of this invention.

Equipment for the ultrasonic cleaning of watches is, as previously indicated, commercially available and often

such equipment (usually with alterations of a relatively minor nature) is ideally suited for accomplishing the sonication, and subsequent, steps of our method. One device which we have found to be particularly suitable in this connection is the Watchmaster Ultrasonic Cleaner unit previously described. That unit is of the nickel transducer type delivering a 60-watt output at approximately 40,000 cycles from a 115 volt, 50–60 cycle at 200 watts input. These particular power and frequency values, however, are not critical to our method, nor is the method functionally limited to the use of nickel transducers.

For the oiling of watch movements or the like having exceptionally small microspaces which must be penetrated with lubricant, best results are achieved by employing frequencies in excess of about 30,000 cycles and acoustic powers of from about 45 to about 65 watts per square inch of sound generator radiating surface. In broad concept, however, wide ranges of frequencies and acoustic power densities are operably functional within the scope of our invention. For example, it is possible to practice the invention in numerous of its individual variations utilizing frequencies of from 1 kc. to 100 mc., as well as even higher frequencies of several hundred mc., and acoustic power densities of any magnitude within the realm of reasonable possibility. Suffice it to say that for most practical applications of our method in the oiling of conventional watch movements, ultrasonic sound frequencies of from about 20,000 to about 100,000 cycles and acoustic power densities of from about 35 to about 70 watts per square inch of sound generator radiating surface are adequate.

The selection of optimum ultrasonic sound frequencies and power requirements for particular functional applicability within the scope of our invention depends upon various factors known to those skilled in the appropriate arts. For example, one advantage of utilizing the lower ultrasonic frequencies (those from about 15 kc. to about 100 kc.) rather than the higher frequencies derives from the relatively longer wave length of the sound produced thereby in the liquid since longer sound waves are transmitted among articles immersed in the liquid with greater ease than are shorter length sound waves such as those generated at higher ultrasonic frequencies. Shorter sound wave lengths are more easily shadowed and absorbed more readily than their longer counterparts with the result that the latter can be transmitted through greater distances without attenuation in a liquid undergoing sonication treatment.

The optimum power requirement for any given application of our process varies with the magnitude and the desired speed of the operation. In general, the higher the desired speed, the larger the amount of power required. Also, the larger the liquid containing vessel, the greater will be the amount of power needed. As previously indicated, these, and other generalities not enumerated, are known to those familiar with sonication technology and for this reason, plus the fact that our invention is not critically dependent upon any particular type of apparatus or sonication technique, no necessity is seen for presently going into further detail on the operational factors of the sonication step of our method. For the same, or similar reasons, no detailed discussion of transducer types is here felt to be necessary. Suffice it to say that, while nickel transducers, as previously indicated, are generally preferred for use in our method, others such as, for example, quartz, barium titanate, cobalt alloy, etc., transducers can be employed within the scope of our invention if desired. The principal reason for the preference of nickel transducers (which reason is also largely applicable with respect to cobalt alloy transducers) is their relative strength by comparison with the piezo-electric crystal (quartz, titanates, etc.) type transducers, such strength, of course, making for rugged sound generator construction.

The steps of our novel and unique oiling process have already been briefly outlined and can be summarized in skeletal form as follows: (1) subjecting the mechanism to be oiled to sonication while it is immersed in a solution of a suitable lubricant in a solvent vehicle; (2) removing the mechanism from the solution and drying it, preferably in a stream of warm air, thereby leaving a thin film of lubricant on the surfaces of its various parts and deposits of lubricant in its internal crevices; and (3) briefly dipping the sonicated and dried mechanism in a rinsing solution, which is a solvent for the aforesaid lubricant, to thereby remove excess lubricant from the mechanism, and particularly from its more exposed parts where oily deposits are undesirable for one reason or another.

To the above three steps can be added an optional fourth step comprising subjecting the dipped mechanism from step (3) to accelerated drying in a stream of warm air, or by equivalent means, to assure complete solvent removal prior to placing of the oiled mechanism in a protective housing. While this final drying step is optional in a broad sense, it is, we feel, an essential one in the case of watches, gauges, and other mechanisms which operate within sealed, or substantially so, housings. As to other mechanisms amenable to treatment by our oiling process, the drying step is optional under some circumstances.

Step (3) of our process is likewise optional or essential, depending upon the same determinative circumstances as those respectively applicable to the final drying step of the process.

It will by now be apparent that numerous embodiment variations of this invention are possible. For example, as emphasized above, there are many ways of varying the operating conditions (ultrasonic frequency, acoustic power, etc.) and sound generator design characteristics (type of transducer, etc.) applicable to step (1) of our method, and this is only one of the three steps of the method. Furthermore, each of the three steps comprises, or can comprise. a plurality of separate procedural techniques, thereby multiplying the number of possible operational and conditional permutations within the scope of our invention. These circumstances, we believe, show that our invention is inherently broad and not subject to narrowly confining limitations of the operating technique, operating condition, apparatus, etc., category. While broad in the above-noted aspects, however, the invention still has recognizable limits setting it apart in the general procedural and functional areas from known lubrication and sonication techniques. The nature and location of these limits should be apparent from the completed disclosure of the invention hereinabove and to follow.

Following is a description of an example of the oiling of popular-brand wrist watches in accordance with the method of our invention. The example description is included for illustrative purposes only and should not be construed narrowly with respect to the materials, conditions and manipulative techniques there set forth.

The movements of two watches, a Bulova 17-jewel man's and a Waltham 17-jewel woman's wrist watch, both in clean but unoiled condition, were subjected to oiling treatment in accordance with the procedure hereinafter described. While there is, as previously indicated, a technical distinction between "oiling" and "lubrication," the two terms are often employed synonymously where there is no particular reason to observe such a distinction. Consistent with this, we have here (as well, incidentally, as at various other places throughout our specification) used those terms, in their various grammatical forms, interchangeably and without regard to any fine shades of distinction therebetween.

Prior to the oiling of the Bulova and Waltham watch movements, each was tested on a watch timing machine and found to be running fast when fully wound, the former by approximately 27 minutes and the latter by

24 minutes per day. The watch timing machine was a Watchmaster G–11 watch timer, a product of Watchmaster Products, Inc., Division of Bulova Watch Company. Hereinafter this timing machine will be referred to simply as the watch timer.

The watch timer measures and records the time rate of a watch's beat (hereinafter referred to as its beat rate) in such a way as to show whether the watch is running fast or slow. The rate data are recorded continuously on a paper tape by the watch timer, the tape being calibrated so as to quantitatively show any deviations, and the directions thereof, of the watch performance from accurate time measurement. The watch timer is, as indicated, a commercially available product and its manner of use and method of operation are commonly known to those skilled in the art, hence, no further discussion thereof is felt necessary here.

Normally, a watch in need of oiling either runs fast or not at all. Thus, beat rate data furnish a means of quickly ascertaining, in many cases, whether a watch is initially in need of lubrication and, if so, the extent to which such a need has been satisfied after an attempted lubrication thereof. It was for this reason that we procured the foregoing beat rate data on the Bulova and Waltham watches, as well as additional data hereinafter set forth. In addition, as will later be more clearly understood, the beat rate data served to help pinpoint optimal operating conditions and techniques (those conducive to most effective oiling) in our method as practiced in the example. We wish to point out, however, that we did not gauge the oiling effectiveness of our method solely on the basis of beat rate data but augmented those data with critically timed visual inspections of the movements throughout the running of the example. The visual inspection of watch movements, with particular emphasis on the capped jewels, for the presence and proper distribution of oil is a reliable way of testing for proper lubrication.

150 ml. of a 2% by volume solution of Versilube F–44, in 1,1,1-trichloroethane was prepared in a graduated cylinder. The 150 ml. of solution was poured from the graduated cylinder into the wash cup of a Watchmaster Ultrasonic Cleaner modified by the addition of one extra cup attached thereto by means of a bracket. The amount of solution was that necessary to achieve an optimum wash solution level in the wash cup.

The Bulova and Waltham watches were placed in positions within a wire mesh basket, of the type heretofore described for use accessory to the ultrasonic cleaner, after which the basket was lowered into the Versilube F–44 solution in the wash cup. The wash cup transducer was then activated and operated for two minutes, during which time the watches were subjected to sonication at a frequency of approximately 40 kc. The basket was then removed from the wash cup and placed in the spin dry cup where it was dried in a stream of air from an accessory drying fan but without spinning of the cup. The fan drying of the watches was continued for four minutes. Following this, the basket containing the watches was consecutively dipped eight times in a bath of 1,1,1-trichloroethane in the hand-rinse cup of the ultrasonic cleaner. Following the separate dips, the basket and watches were dried in the spin-dry cup in the above-described manner, except that each drying period was two minutes instead of four.

Each of the eight dips was carried out by immersing the basket to its maximum possible depth in the 1,1,1-trichloroethane in the hand-rinse cup; turning it first through an approximately 180° rotation (around its axis of symmetry) in one direction and then through approximately 180° in the opposite direction; and, finally, removing the basket from the hand-rinse cup. After each dip and subsequent two minutes of drying, each of the watches was tested for beat rate on the Watchmaster G–11 watch timer. Following these activities, the two watch movements were sonicated for four minutes in pure 1,1,1-trichloroethane and again tested for beat rates on the watch timer. The results of the watch timer tests are set forth below in Tables I and II.

TABLE I

Bulova 17-jewel movement

Condition of watch:	Rate of running
Cleaned and unoiled	27 min./day fast.
After 2 min. of oiling and before dipping in solvent	Slight, irregular movement of balance wheel.
After 1st dip	20 min./day fast.
After 2nd dip	Did not make a record
After 3rd dip	of this.
After 4th dip	13 min./day fast.
After 5th dip	2 min./day fast.
After 6th dip	Watch was running at
After 7th dip	the proper beat (not fast or slow). 2 min./day fast.
After 8th dip	Did not make a record
After sonication for 4 min. in pure 1,1,1-trichloroethane	of this. 3 min./day fast. 15 min./ day fast.

TABLE II

Waltham 17-jewel movement

Condition of watch:	Rating of running
Cleaned and unoiled	24 min./day fast.
After 2 min. of oiling and before dipping in solvent	Slight, irregular movement of balance wheel.
After 1st dip	18 min./day fast.
After 2nd dip	9 min./ day fast.
After 3rd dip	7 min./day fast.
After 4th dip	1 min./day fast.
After 5th dip	1 min./day fast.
After 6th dip	Did not make a record of this.
After 7th dip	Did not make a record of this.
After 8th dip	1.5 min./day fast.
After sonication for 4 min. in pure 1,1,1-trichloroethane	22 min./day fast.

The above results are significantly revealing in several important respects. Before discussing the effect of the after-oiling solvent dips on the running performances of the watches, attention is directed to the second item in each of the tables showing the results of watch timer tests conducted subsequent to the oiling and drying, but prior to solvent (1,1,1-trichloroethane) dipping, of the watches. These results, especially by comparison with those of the watch timer tests on the watches in their initially unoiled condition (first itemized entry in each of the tables), show that the oiling so overlubricated the watch movements as to cause fouling and consequent prevention of proper functioning thereof. This clearly evidences the previously indicated need of followup solvent dip treatment of watch movements oiled in accordance with the method of this invention.

It should be explained that no significance attaches to the omission of certain watch timer test results from the foregoing tables. All eight of the indicated solvent dips were actually made and a sufficient number of watch timer tests were run to establish a tendency of the running rates of the watches to approach perfect timing accuracy as the number of precedent solvent dips increased and to then revert to increasingly faster beat tempo as the number of dips increased beyond the point of optimum timing accuracy. The reasons for making the watch timer tests were satisfied by the representative results in the tables and nothing was observed during the obtaining of those

results to indicate deviation from the running rate-number of dips relationship noted. Consequently, our conclusion of lack of significance in the indicated data gaps in the tables is bottomed on sound evidence and judgment.

It is worthy of note that the only reason for drying the watch movements between the solvent dips of this example was to permit subsequent testing of the movements on the watch timer. Where no such testing is required, as in commercial applications of our oiling method, drying between solvent dips is unnecessary (although not harmful) and can be dispensed with. Notwithstanding anything heretofore indicated to the contrary, where no post-solvent dip running rate determinations were made in this example there was no necessity for drying the dipped movements prior to redipping them. This should not be taken to mean, however, that such drying between dips has no influence on the relative proportion of lubricant stripped from a watch movement by each dip. In fact, the drying might have sufficient influence on quantitative lubricant removal to alter the number of dips required for achieving optimum oil deposition in a watch movement from the number required without such drying. The point is that even if the drying treatment has such an effect its elimination is still desirable because this simplifies the practice of our method to a sufficient extent to more than compensate for any possible increase in the number of solvent dips thereby entailed. A drying step between the initial sonication and any subsequent solvent dipping steps of our method is, however, essential in most cases.

Turning now to consideration of the results of this example, a review and comparison of Tables I and II shows that five solvent dips yielded optimum time keeping accuracy for each of the tested watches, thus indicating, as previously explained, that it was then properly oiled. The importance of this, and the manner, previously discussed, in which the running rates of the watches approached the optimum as the number of solvent dips increased, and then backed away as the number of dips advanced still higher is that it gives an indication of the criticality of solvent to our dipping method, as applied to watch oiling, and the necessity of proper time exposure of an oiled watch movement to solvent for the removal of oil in the proper quantities from its more exposed surfaces consistent with prior teachings herein. It is interesting to note that overoiling, up to a point, as well as underoiling, causes an otherwise normal watch movement to run fast. Thus, as both Tables I and II illustrate, the oiled watches ran fast until the fifth dip, prior to which they were overoiled, and again ran fast after six or more dips at which times they were underoiled.

While the selective removal of oil from a watch movement to yield a properly lubricated mechanism sounds like a difficult feat to accomplish, one feature of this invention is the fact, discovered by us, that this result is readily achievable by means of the fairly simple solvent dipping technique taught herein. The specific dipping procedure here described can be varied in numerous ways within the scope of our invention but the basic idea is so simple and the means of determining an optimumly effective combination of operating conditions (number of dips, immersion time per dip, etc.) so well within the skill of the routineer, once the basic idea is understood, that no further discussion, or exemplification of dipping techniques seems necessary. Suffice it to say that the preferred number of solvent dips, and manner of manipulating the watch movement under the solvent during each dip, will vary with changes in apparatus, lubricant, solvent, and the other factors involved in the practice of our oiling method. While the solvent dip feature of our invention has been discussed in terms suggestive of the plural, the invention is not so limited and even one dip (by dip is meant full or partial immersion in the solvent for any period of time) will suffice so long as it accomplishes the purpose, at least to some degree, for which it is intended. As is, of course, normally the case, it is possible to operate within the scope of our invention under other than optimal conditions and circumstances.

The final item in each of the above tables (running rate after sonication in pure solvent) illustrates the point heretofore made that our solvent dipping procedure is ineffective if accompanied by sonication due to the consequent removal of too much lubricant from the watch movement. More specifically, the fast running rates of both the Bulova and Waltham watch movements after four minutes of sonication in the 1,1,1-trichloroethane bear witness to a generally incapacitating loss of lubricant from each as a result thereof.

It will by now be more than apparent that there are numerous possible forms of this invention which vary in a great many ways within its overall scope as taught and claimed therein. Heretofore, emphasis has been directed to the narrower aspects of the invention with consequent neglect of its broader ones. The invention in its broadest concept, as we visualize it, comprehends the concurrent immersion, wholly or partially, of a mechanism in a coating liquid and sonication thereof for the purpose of forcing the liquid into all minute crevices or interstices, and into contact with all surfaces, of said mechanism. The term "mechanism," as here applied, is intended to connote any assembly of parts amenable to treatment by the method of our invention, whether or not such assembly has moving parts. The "coating liquids" contemplated are those liquids of the class normally intended for application and subsequent adherence to solid surfaces, deposition in the minute crevices of mechanical assemblies, etc., for purposes of providing insulating, protection, friction reduction properties, or the like, in their present or altered forms, to their surfaces of adherence or contact. Examples of such coating liquids are lubricants, paints, varnishes, etc. The coating liquid can be utilized in the method of our invention in pure, solvent or vehicle diluted, or other form. When a lubricant is employed as the coating liquid in the preferred watch oiling embodiment of our invention it is, as taught herein, used in diluted form in a solvent solution thereof.

We are aware that the general idea of using sonication to bring about more effective contact between cleaning solutions and the parts of watch movements, or other mechanisms, is known and have, in fact, already discussed this at some length. The broad concept of our unique method is different in purpose and method of accomplishment, however, from the known sonication cleaning procedures. For one thing, to repeat in brief summary what has already been covered herein in some detail, the viscosity and surface tension characteristics of our contemplated coating liquids normally mitigate against their satisfactory penetration into the minute crevices or interstices of immersed mechanisms. When immersion is accompanied by sonication, however, the adverse effect of these liquid characteristics is overcome, thus permitting the flow of coating liquids into minute inner recesses, and consequent contact of all surfaces, of said mechanisms.

As will be apparent from the foregoing observations, the functional object of our sonication treatment is to so effect the properties of the involved coating liquid as to permit its rapid entry, not otherwise achievable, into and through narrow spaces within the body of an immersed mechanism and consequent migration to its intended sites of deposition therein. The prior art sonication procedures, on the other hand, purport to bring about better interfacial contact between cleaning solutions, or the like, and solid surfaces, to achieve more effective cleaning, or other, contactual function. The conceptual distinctions between our sonication method and the previously known ones is believed apparent from the foregoing comments, considered in conjunction with the character differences between our more viscous coating liquids and the less viscous cleaning solutions or the like, of the prior art. The narrower embodiments of our invention, such as the herein

emphasized watch oiling method, typically include our unique solvent dipping feature, for partial removal of the applied coating liquid, which feature has no counterpart, actual or suggested, anywhere insofar as we are aware.

There are numerous applications in addition to watch oiling for which the method of this invention has utility. For example, the method has applicability in the field of miniaturized instrumentation where the contact of all possible surfaces of instrument assemblies with lubricants or the like is necessary or desirable. Other possible areas of use include the painting of generator parts, dial phones, and other complex devices having minute internal hollows, passages, etc. In connection with our watch oiling method, it is worthy of note that this procedure has even greater effectiveness with watches of closer internal tolerances than with others, or, in other words, the tougher the challenge, the more effective the method.

The present invention can be practiced in any of the numerous ways taught or suggested herein to those skilled in the art. All such practice is considered to be a part of the invention provided it falls within the scope of the appended claims. For example, where the method of the invention encompasses the use of a coating liquid-solvent mixture (as exemplified by our watch oiling lubricant-solvent mixture) such does not necessarily have to be a true solution but could be, for instance, an ultrasonically, or otherwise, formed emulsion of lubricant and "solvent," or a mixture partly true solution and partly emulsion. Thus, a more accurate generic term for our "solvent," as here contemplated, would be "vehicle." Solubility of the lubricant in the dip solvent of the watch oiling method is, however, a necessity in most cases.

The invention has been described in considerable detail in order to comply with the patent laws by providing a full public disclosure of at least one of its forms. However, such detailed description is not intended in any way to limit the broad features or principles of the invention, or the scope of patent monopoly to be granted.

We claim:

1. A method of lubricating a complex assembly comprising:
   (a) immersing the assembly in a lubricant coating liquid containing a vehicle and a lubricant, said vehicle being of greater volatility than said lubricant;
   (b) subjecting the assembly and surrounding liquid to sonication;
   (c) removing the thus-sonicated assembly from the liquid with some of said liquid adherent thereto;
   (d) drying vehicle from liquid adherent to the thus-removed assembly leaving residual lubricant thereon;
   (e) immersing the thus-dried assembly in a body of solvent for said lubricant until lubricant is partially dissolved therefrom; and
   (f) removing said assembly from said body of solvent.

2. A method of lubricating a complex assembly comprising:
   (a) immersing the assembly in a solution of suitable lubricant in a first solvent therefor of greater volatility than said lubricant;
   (b) subjecting the assembly and surrounding solution to sonication;
   (c) removing the thus-sonicated assembly from the solution with some of said solution adherent thereto;
   (d) drying solvent from solution adherent to the thus-removed assembly leaving residual lubricant thereon;
   (e) immersing the thus-dried assembly in a body of a second solvent for said lubricant until lubricant is partially dissolved therefrom and
   (f) removing said assembly from said body of second solvent.

3. The method of claim 2 in which the complex assembly is a watch movement.

4. The method of claim 2 in which the lubricant is a silicone lubricant.

5. The method of claim 2 in which the lubricant is methyl tetrachlorophenyl silicone.

6. The method of claim 2 in which the lubricant is a silicone lubricant having a viscosity of from about 25 to about 200 centistokes.

7. The method of claim 2 in which the first solvent for said lubricant is one having a drying time of from about half a minute to about five minutes.

8. The method of claim 2 in which the first solvent for said lubricant is a halogenated solvent.

9. The method of claim 2 in which the first solvent for said lubricant is 1,1,1-trichloroethane.

10. The method of claim 2 in which the sonication is effected by introducing sound vibrations into said solution at a frequency of from about 20,000 to about 100,000 cycles per second at a power density of from about 35 to about 70 watts per square inch of sound generator radiating surface.

11. The method of claim 2 in which the sonication is effected by introducing sound vibrations into said solution at a frequency in excess of about 30,000 cycles per second at a power density of from about 45 to about 65 watts per square inch of sound generator radiating surface.

12. A method of lubricating a complex assembly comprising:
   (a) immersing the assembly in a solution of methyl tetrachlorophenyl silicone in 1,1,1-trichloroethane;
   (b) subjecting the assembly and surrounding solution to sonication with sound vibrations having a frequency of about 40,000 cycles per second at an accoustic power of from about 45 to about 65 watts per square inch of sound generator radiating surface;
   (c) removing the thus-sonicated assembly from the solution with some of said solution adherent thereto;
   (d) drying 1,1,1-trichloroethane from solution adherent to the thus-removed assembly leaving residual methyl tetrachlorophenyl silicone thereon;
   (e) dipping the thus-dried assembly in a body of solvent for said methyl tetrachlorophenyl silicone whereby the silicone is substantially dissolved from parts requiring no lubrication but left in place in innermost recesses of said assembly requiring the presence of lubricant; and
   (f) removing solvent adherent to the thus-dipped assembly by an accelerated drying of said assembly.

13. The method of claim 12 in which the solution of methyl tetrachlorophenyl silicone in 1,1,1-trichloroethane has a concentration of about 2% by volume of the former.

14. The method of claim 12 in which the solvent into which the assembly is dipped in step (e) is 1,1,1-trichloroethane.

15. A method of lubricating a complex mechanism without disassembly thereof, comprising the steps of immersing the mechanism in a liquid bath containing a halogenated solvent in which a silicone lubricant is dissolved in a concentration of about 0.5 to 5% by volume, and applying ultrasonic energy to the bath while keeping the mechanism immersed therein so as to disperse lubricant throughout the mechanism.

16. A method of lubricating a complex mechanism without disassembly thereof, comprising the steps of immersing the mechanism in a liquid bath containing both a lubricant and a vehicle, applying ultrasonic energy to the bath while keeping the mechanism immersed therein so as to disperse lubricant throughout the mechanism, removing the mechanism from the bath and drying it to evaporate the vehicle, and thereafter at least partially immersing the mechanism in a solvent for said lubricant without sonication so as to remove excess lubricant from some portions of the mechanism.

17. The method of claim 16 wherein said lubricant is a silicone lubricant.

18. The method of claim 17 wherein said vehicle is a halogenated solvent.

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