United States Patent [19]

Brouwer et al.

[11] **3,822,820**

[45] **July 9, 1974**

[54] **SONIC AGITATION OF MOLTEN METAL**

[75] Inventors: **Nicholaas L. Brouwer,** Allegheny Township, Westmoreland County; **David E. Smucker,** New Kensington, both of Pa.

[73] Assignee: **Aluminum Company of America,** Pittsburgh, Pa.

[22] Filed: **Sept. 20, 1973**

[21] Appl. No.: **398,946**

[52] **U.S. Cl.** **228/1,** 228/56
[51] **Int. Cl.** **B23k 1/06**
[58] **Field of Search** 118/429; 228/1, 36, 56

[56] **References Cited**

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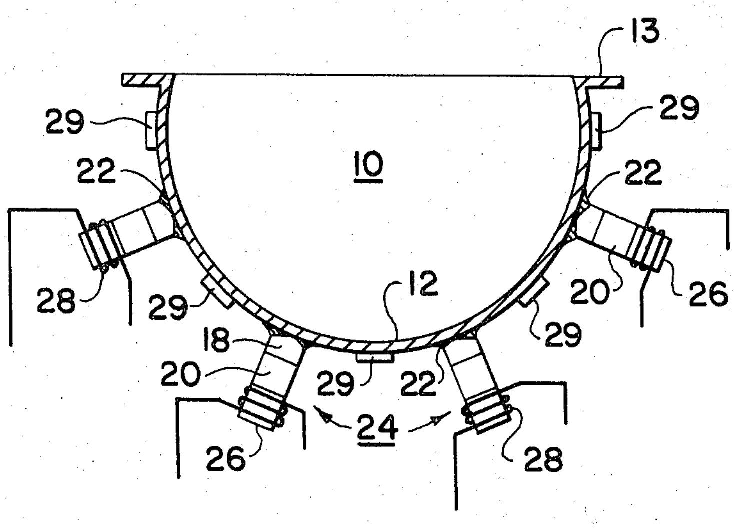
Primary Examiner—Gerald A. Dost
Attorney, Agent, or Firm—Elroy Stickland

[57] **ABSTRACT**

Simultaneous fluxless joining, tinning and/or coating of components or workpieces is effected by the use of a sonically agitated molten metal bath maintained at a uniform temperature and contained in a vessel comprised of a curved (in cross section), solid, unitary shell. The sonic agitation is provided by multiple arrays of sonic energy transducers disposed about and along the shell, and in energy transfer relationship with the bath via the shell. The arrays of transducers are grouped, and the groups individually energized by sonic power generators each having means for controlling the sonic power output thereof, as well as the sonic frequency, to provide individually controllable zones of sonic energy within the vessel and molten metal bath.

11 Claims, 2 Drawing Figures



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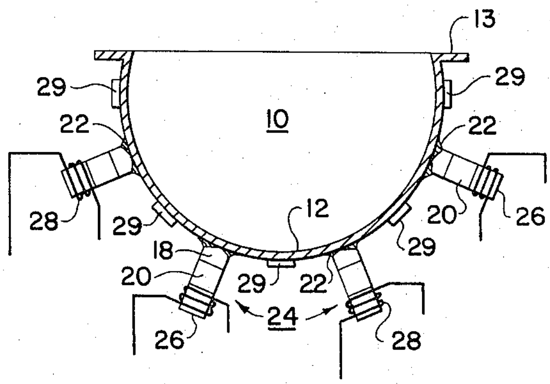

FIG. 1

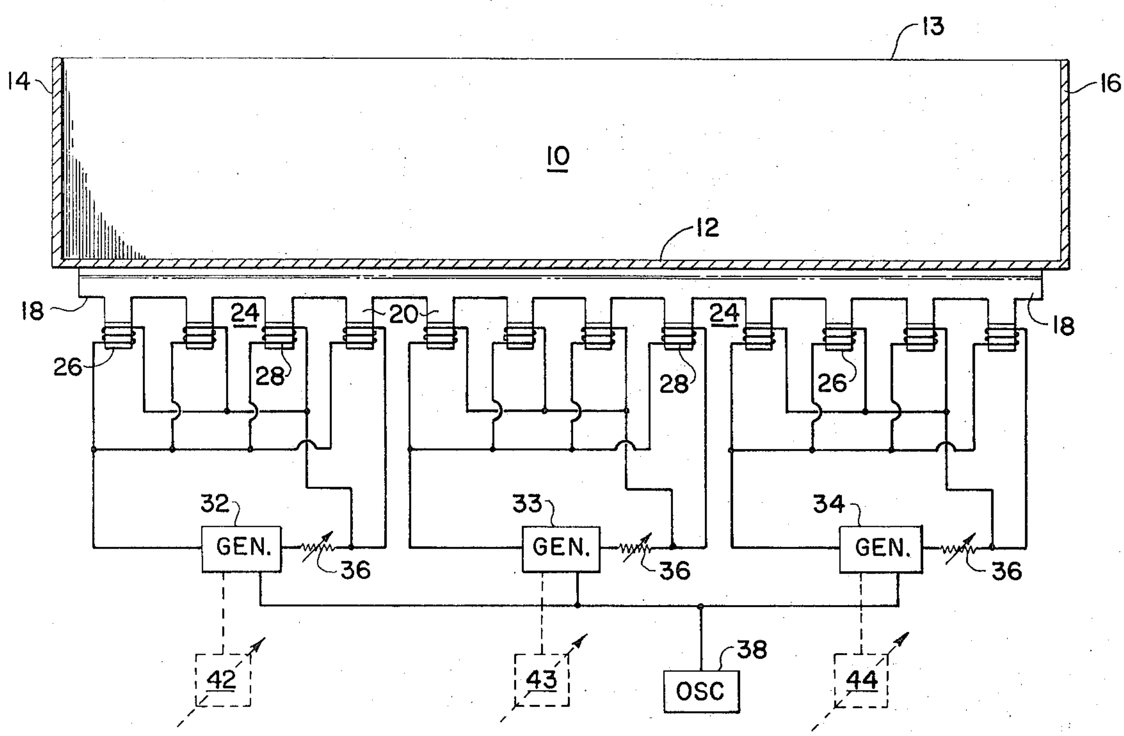

FIG. 2

SONIC AGITATION OF MOLTEN METAL

BACKGROUND OF THE INVENTION

The present invention relates generally to the sonic agitation and resulting cavitation in a molten metal bath, and particularly to an arrangement whereby, in a solder bath medium, maintained at a uniform temperature, cavitation is produced to provide reliable, consistant joining, tinning and/or coating of components without the need of flux, and of the type required for industrial, production purposes. The term "sonic energy" as used herein, refers to subsonic, sonic or ultrasonic frequency energies.

The use of sonic energy sources to agitate molten metal baths are well known. However, past and present apparatus employing such sources have certain disadvantages for ambient and elevated temperature applications in an industrial environment. The majority of vessels employed in the industry for containing sonically agitated molten metal have a generally rectangular or square configuration in cross section, the vessel being either cast in such a configuration or fabricated from metal plates welded together along abutting edges to form a square or rectangularly shaped vessel. Such a vessel configuration provides a bottom shell surface of limited area for attaching sonic transducers, thereby limiting the number of transducers that can be used, and thus limiting the sonic power transmitted into the molten metal. Generally, the side walls of a square or rectangular shaped vessel do not readily lend themselves for the attachment of a large number of sonic energy transducers because the side walls are usually employed to apply heat to the vessel and thus to the molten metal contained therein.

Further, rectangularly shaped vessels tend to be highly rigid such that the mechanical forces produced in the shell of the vessel by the sonic agitation, and resulting cavitation of the molten metal, fatigue the shell, particularly along the right angle intersections of the side and base walls thereof, the intersections forming areas of stress concentration.

If the vessel is fabricated by welding square or rectangular plates together, the welds are located along the intersections of the sides and base and thus at the areas of stress concentration such that welds are weakened by the sonic agitation and cavitation. Those welds that extend lengthwise of the vessel are especially susceptible to the detrimental effects of the mechanical forces generated within the vessel shell since the magnitude of the sonic energy is substantially greater in the more central areas of the base of the vessel.

In addition, welded areas of a vessel may be subject to corrosive attack by components of the molten medium, such as the zinc in a zinc solder bath. As a result of such fatigue and attack, the welds and vessel walls are weakened such that over a period of time the vessel must either be repaired or replaced.

A problem associated with past and present sonic energy soldering techniques employing a bath of molten metal solder is the unevenness or non-uniformity of the agitation and cavitation along the base of the vessel, where the transducers are attached, such that sonically quiescent or dead zones occur within the medium of the bath along with zones having a high concentration of sonic energy. Such zones become particularly critical when a plurality of components having a multiplicity of joining surfaces, occupying a broad area within the vessel, are immersed in the bath to effect simultaneous soldering of the joining surfaces. An example of a structure having such multiplicity of joining surfaces is a heat exchanger having a multiplicity of socket joints formed by U-shaped, return bend tubes disposed on the ends of elongated tubes of the heat exchanger to serially connect the tubes together. In the dead or less active zones of the solder bath, little or no soldering or joining takes place so that any of the multiple joining surfaces located in such zones are either not soldered at all or are inadequately soldered and joined. Such a soldering arrangement is thus unsuitable for soldering heat exchangers since all joints in a heat exchanger must be equally and satisfactorily soldered or the heat exchanger is or soon becomes a defective unit with normal use thereof.

BRIEF SUMMARY OF THE INVENTION

Briefly, the present invention overcomes the problems and disadvantages of prior and present apparatus employed to sonically agitate molten metal baths by the use of a vessel comprised of a unitary, solid, curved shell in cross section, the unitary shell providing a vessel having no welds extending between the ends of the vessel, and no welds at all if the vessel is made as a one piece unit, such as would be provided by a casting or forging process, for example. In this manner, there are no welds to be severely attacked by a component or components of the molten metal bath and by the cavitation produced in the bath medium.

Maximum uniformity of sonic agitation and resulting cavitation of the molten metal within a prescribed work area in the vessel is effected by use of circumferential arrays of sonic energy transducers located around the curve of the vessel shell and disposed in sonic energy transfer relationship with curved, outer surface of the shell.

Preferably, the arrays of sonic energy transducers are attached respectively to corresponding arrays of sonic energy coupling devices projecting outwardly from the curved, outer surface of the vessel shell.

The arrays of sonic transducers and coupling devices are divided into groups and energized by a corresponding plurality of generators to provide individual control and/or tuning of the groups of transducers and thus provide sonic power input control to the areas of said vessel associated respectively with the corresponding transducer groups.

Between the coupling devices and disposed closely adjacent the vessel shell are located heaters that heat and maintain the molten metal bath at a uniform, elevated temperature, i.e., for example, on the order of 760°F, the transducers being preferably located away from the heaters by the extent of coupling devices.

THE DRAWING

The invention, along with its advantages and objective, will best be understood from consideration of the following detailed specification and the accompanying drawing in which:

FIG. 1 is a cross sectional view of a soldering vessel of the invention comprised of a curved shell, with sonic energy transducers attached to the curved, outside surface of the shell in accordance with the principles of the invention; and

FIG. 2 is a side elevation view of the structure of FIG. 1, with the vessel proper being shown in section.

PREFERRED EMBODIMENT OF THE INVENTION

Referring now to FIG. **1** of the drawing, a soldering vessel or tank **10** is shown in cross section, the vessel being comprised of a unitary, solid and curved wall or shell **12**, the curve of the shell preferably extending the full length thereof, as indicated in FIG. **2**. As shown in the figures, the shell may have opposed, outwardly extending flange portions **13** that extend the length thereof.

The vessel **10**, being primarily a single piece unit has no weld areas extending the length thereof for attack by components of the molten metal (not shown) contained therein or by the cavitation of the bath, as discussed earlier. The vessel includes end wall portions **14** and **16**, as shown in FIG. **2**, which may be an integral, unwelded portion of the shell **12**, or, the end walls **14** and **16** can be made separately from shell **12** and joined to the ends of the shell by weld seams (not shown) located at the intersections of the curved ends of the shell and the planar surfaces of the end walls. Such end welds and seams, however, are not subject to severe sonic agitation and resulting cavitation of the bath since the intensity of sonic energy adjacent the ends of the vessel is minimal in comparison to that existing along the more central areas of the vessel.

On and around the outside surfaces of the curved shell **12** are mounted, as shown in FIG. **1**, four, spaced apart elongated sound energy coupling bars **18**, (only one such bar being visible in FIG. 2), the number (four) of coupling bars depicted in FIG. **1** being given only for purposes of illustration. As explained hereinafter, the number of coupling bars, coupling extensions and sonic energy transducers are chosen on the basis of such factors as the amount of sonic power desired or required for a particular vessel and operation.

The coupling bars **18** may be formed as an integral part of the shell **12**, thereby providing a continuous path between the bars and shell for maximum transfer of sonic energy into the vessel from the bars.

As shown in FIG. **2**, the coupling bars have outwardly projecting sound energy coupling extensions, such as horns or studs **20** spaced along the length of the bars, that provide multiple arrays of the coupling devices extending lengthwise of the vessel. In FIG. **1**, only one such array is visible.

If the coupling bars **18** are not formed as an integral part of shell **12**, the bars should be attached to the shell in a manner that presents a minimum acoustical impedance to the sonic energy to be directed into the vessel. This can be accomplished with means and materials that produce a good metallurgical and sonic bond between each bar and the shell, for example, as provided by the full penetration welds **22** shown in FIG. **1**, which welds extend the length of the bars. Full penetration welds and good metallurgical bonds of similar materials provide minimum acoustical impedance to the sound energy generated by sonic energy transducers **24** attached to the coupling extensions **20**, and presently to be described, to obtain maximum transfer of the sound energy from the transducer surfaces, coupling extensions and bars to the shell **12**, and thus into the bath contained in the vessel **10**.

With the coupling bars **18** extending along the length dimension of the vessel, the bars serve further to strengthen the vessel, and to uniformly distribute sonic energy over the vessel area.

Sonic energy transducers **24** are shown attached to the ends of the coupling extensions **20** remote from the shell **12**, the transducers being preferably magnetostrictive devices schematically represented in the figures by cores **26** and windings **28**, the transducers, like the coupling extensions, being circumferentially spaced apart around the curve of the shell, and along the length thereof (FIG. **2**) to provide multiple arrays of sonic sources. The transducers **24** are preferably magnetostrictive because such transducers have metallic cores that can be brazed or welded to a metal surface in a manner that presents a minimum impedance to the sonic energy developed in the core by its winding while simultaneously providing a high strength joint particularly suitable for industrial purposes. For example, if the coupling extensions are stainless steel and the cores of the transducers are comprised of nickel or nickel alloy laminations, the laminations can be joined to the ends of the coupling extensions by silver soldering or brazing the joining materials providing a high strength, good metallurgical bond between the laminations of the transducers and the stainless steel of the coupling extensions, and thus a minimum acoustical impedance at the interfaces between the transducer cores and the coupling extensions. Further, magnetostrictive transducers are reliable, rugged devices that can withstand the high temperatures associated with molten metal.

In addition, to further insure maximum transfer of acoustical energy into the molten metal within the vessel **10** the thickness dimension of the shell **12** and the length of each coupling extension **20** (including the bar portion **18**) together is preferably one half wave length long at the resonant frequency of transducers **24.**

As indicated only schematically in FIG. **1** of the drawing, between the peripherally spaced locations of the coupling bars and transducers, and extending lengthwise of the vessel **10** are located heating devices **29** for heating and maintaining the molten metal bath within the vessel **10** at an elevated, molten temperature. Heating devices suitable for such a purpose are preferably elongated, electric resistance heating rods located in close proximity to the vessel shell **12** but with minimum physical contact therewith to minimize damage of the rod elements by the sonic vibration. In combination with such rods, it is preferable to use reflectors located behind the rods and facing in the direction of the vessel shell, the reflectors with the rods, serving to direct radiant heat, i.e., the heat radiated by the rods, at the vessel shell, when the rod elements conduct appropriate amounts of electrical current.

Such heating devices are particularly advantageous in heating an industrial soldering vessel since they can be conveniently disposed to evenly heat the vessel and soldering bath, and can be precisely, automatically controlled by thermocouples, and associate electrical apparatus, operatively associated with the vessel or with the solder content within the vessel.

The desirability of such control is especially critical when cavitation of the soldering bath is employed in the soldering process. The cavitation phenomenon can be aggressive to the point of attacking and destroying the metal of components immersed in the bath. The velocity of sound energy in the bath, which energy produces the cavitation, is itself a function of the temperature of the bath. Thus, by evenly and precisely controlling the temperature of the bath through the vessel, control of the velocity of the sound, and thus cavitation, in the bath can be effected throughout the bath medium. In this manner, only the oxides and other impurities on the components to be soldered are removed therefrom by the cavitation, and since the cavitation is relatively uniform throughout the bath, the soldering is even and effective regardless of the location of the components within the bath.

There are substantial variations in the sizes and configurations of vessels designed to hold molten metal for sonic agitation, and in the workpieces and components disposed in the molten metal for coating the joining purposes. If, for example, the components to be soldered in a soldering bath occupy only a limited area within a large vessel containing the bath, it is desirable, if for no other purpose than the saving of electrical power, to activate with sonic energy substantially only the area of the bath occupied by the components.

In addition, vessels having different sizes and shapes have difference sonic resonant frequency characteristics, and these characteristics change to an extent when a workpiece or pieces are disposed in the molten metal bath, the degree of change depending, in turn, upon the size and configuration of the workpiece. Thus, in a vessel containing a molten metal medium designed to operate efficiently at the resonant frequency of a particular sonic energy transducer, the load on the transducer is changed somewhat when the workpiece or pieces are inserted in the vessel and molten metal thereby changing somewhat the resonant frequency of the transducer. Thus, to effect optimum, maximum sonic energy transfer in a vessel containing a molten metal medium having workpieces disposed thereof of a particular number and configuration, it is desirable to be able to "tune" the vessel or portions thereof by applying thereto a sonic frequency that is the resonant frequency of the transducer as it is affected by the load, i.e., by the configuration of the workpiece and the alteration of the vessel configuration when the workpiece is disposed in the vessel. The tuning accomplished here effects optimum conversion of the electrical energy, produced by generators presently to be described, to mechanical, sonic energy at the resonant frequency of the total vessel and molten metal structure.

With these considerations in mind, the present invention includes grouping the transducers and coupling extensions to provide selective control of sonic power into the vessel, and selective tuning of the vessel, as shown and suggested schematically in FIG. 2. More particularly, the twelve transducers **24** associated with each coupling bar **18** are shown electrically divided into three groups of four transducers by being respectively electrically connected to three electrical power generators **32, 33** and **34** designed to energize the three groups at their resonant frequency. Thus, with the arrangement depicted in the drawing, in which four coupling bars **18** each having twelve coupling extensions **20** and transducers **24,** twelve generators are required, though only three are shown in FIG. **2.** This grouping, however, as well as the number of transducers and coupling devices, is given by way of example only, the number of generators, transducers and groups of transducers being chosen on the basis of such factors as the size of the vessel to be employed and the power requirements for a particular volume and type of molten metal to be agitated.

As depicted in FIG. **2** by variable resistances **36,** each of the generators has means to control the level of its power output to its particular group of four transducers, thereby providing means to control both the magnitude and the locations of sonic energy input to the molten metal within vessel **10.**

All of the generators can be triggered synchronously by a single, common, variable oscillator **38** (FIG. **2**), designed to oscillate approximately at some range around the resonant frequency of the transducers **24,** or, each generator can be individually triggered and tuned by its own variable oscillator, such oscillators being shown in dash outline in FIG. **2,** and indicated by numerals **42, 43** and **44.** With a variable frequency oscillator associated with each generator, the electrical output of each generator, and thus the sonic frequency produced by its associated array of transducers, can be tuned to the resonant frequency of the transducers as they are loaded and affected by the geometry of the vessel **10** with workpieces disposed therein. In this manner, maximum transfer of sonic power to the molten metal, and to the area thereof associated with the particular group of transducers being tuned, is obtained.

The term "solid" as used herein in reference to the vessel refers to a shell structure that has no or substantially no perforations or openings.

While the invention has been described in terms of preferred embodiments, the claims appended hereto are intended to encompass all embodiments which fall within the spirit of the invention.

Having thus described our invention and certain embodiments thereof, we claim:

1. In combination, a vessel for containing molten metal at elevated temperatures, the vessel comprising a unitary, solid, curved shell in cross section, multiple arrays of sonic energy transducers spaced apart about and along the outside of said shell, and in sonic energy transfer relationship with the shell for directing sonic energy through the shell and into a work area of the vessel when the transducers are energized, a plurality of electrical power generators having means for individually controlling the power output thereof, and an oscillator for commonly, synchronously triggering said generators, groups of the arrays of transducers being respectively electrically connected to and energized by said generators for providing individually controllable zones of sonic energy within the vessel, and means for uniformly heating the vessel and molten metal.

2. The combination of claim **1** in which the arrays of sonic energy transducers are attached respectively to corresponding arrays of sonic energy coupling devices disposed about and along the outside of the curved shell and in sonic energy transfer relationship with the shell.

3. The combination of claim **2** in which the coupling devices are attached to the vessel shell by full penetration welds.

4. The combination of claim **2** in which the coupling devices are formed as an integral part of the vessel shell.

5. The combination of claim **2** in which the coupling devices include elongated, sound energy coupling bars extending lengthwise of the vessel.

6. The combination of claim 2 in which the coupling devices include arrays of outwardly projecting, sonic energy coupling extensions disposed in sonic energy transfer relationship with the vessel shell.

7. The combination of claim 6 in which the coupling devices include elongated, sound energy coupling bars extending lengthwise of the vessel, and the coupling extensions form an integral part of the elongated coupling bars.

8. The combination of claim 1 in which the heating means comprise a plurality of heaters disposed around the outside surface of the vessel shell.

9. In combination, a vessel for containing molten metal at elevated temperatures, the vessel comprising a unitary, solid, curved shell in cross section, multiple arrays of sonic energy coupling devices spaced apart about the outside of said shell, with one end of each device disposed in sonic energy transfer relationship with the shell for directing sonic energy through the shell, multiple arrays of sonic energy transducers respectively attached to the ends of said coupling devices remote from the shell, the arrays of devices and transducers being capable of directing the major portion of the sonic energy produced by the transducers, when the transducers are energized, into a work area of the vessel, a plurality of electrical power generators each having an oscillator that individually triggers and tunes the generator at the frequency of said oscillator, groups of the arrays of the transducers being respectively electrically connected to and energized by the generators to provide individual tuning of zones of sonic energy within the vessel for optimum transfer of sonic energy within said zones, and means for uniformly heating the vessel and molten metal.

10. The combination of claim 9 in which the vessel includes two wall portions closing the respective ends of the shell, and joined to the ends of the shell.

11. In combination, a vessel for containing molten metal at elevated temperatures, the vessel comprising a solid, curved shell in cross section and wall portions closing the respective ends of said shell, said wall portions being welded to the ends of said shell, multiple arrays of sonic energy coupling devices spaced about the outside of the shell, with one end of each device disposed in sonic energy transfer relationship with the shell, multiple arrays of sonic energy transducers respectively attached to the ends of the coupling devices remote from the shell, the arrays of devices and transducers being capable of directing the major portion of the sonic energy produced by the transducers, when the transducers are energized, into a work area of the vessel, a plurality of electrical power generators having means for individually controlling the power output thereof and an oscillator for commonly, synchronously triggering said generators, groups of said arrays of transducers being respectively electrically connected to and energized by said generators for providing individually controllable zones of sonic energy within the vessel, and means for uniformly heating the vessel and molten metal.

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