Oct. 9, 1962 W. J. HELWIG 3,057,130

APPARATUS FOR PROCESSING ARTICLES OR MATERIALS IN A CONTINUOUS FLOW OPERATION

Filed March 5, 1959 3 Sheets-Sheet 1

Fig. 1.

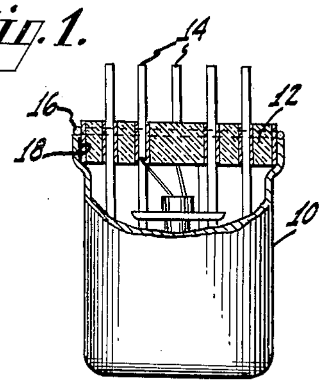


Fig. 2.

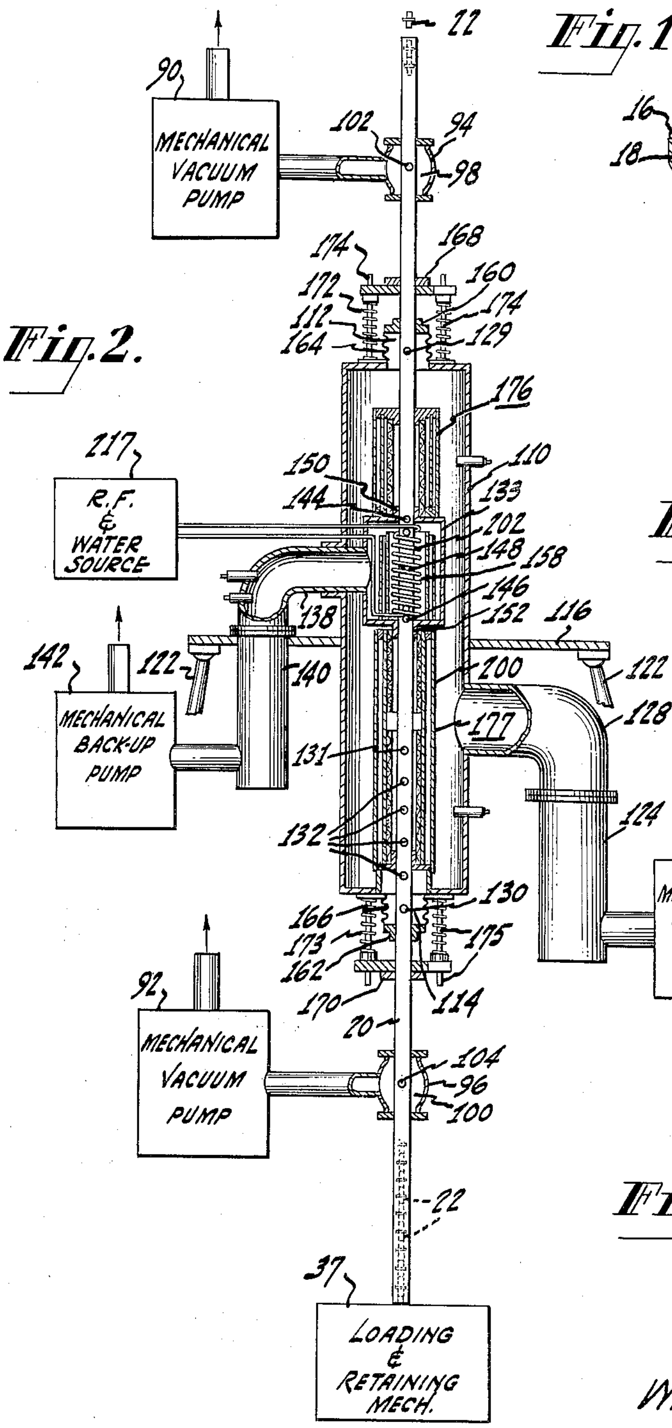


Fig. 3.

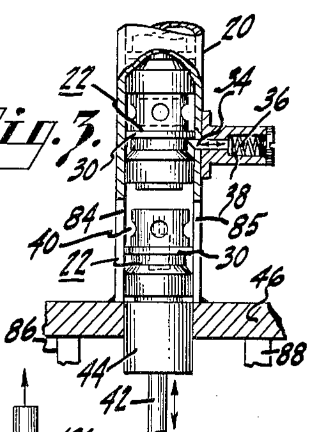
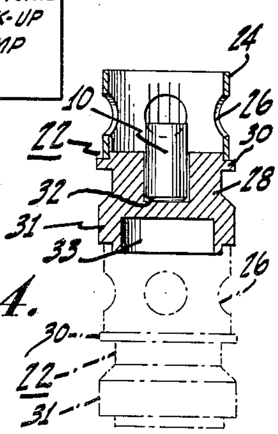


Fig. 4.



INVENTOR.
WILLIAM J. HELWIG

BY L. A. Larew

ATTORNEY

Fig. 5.

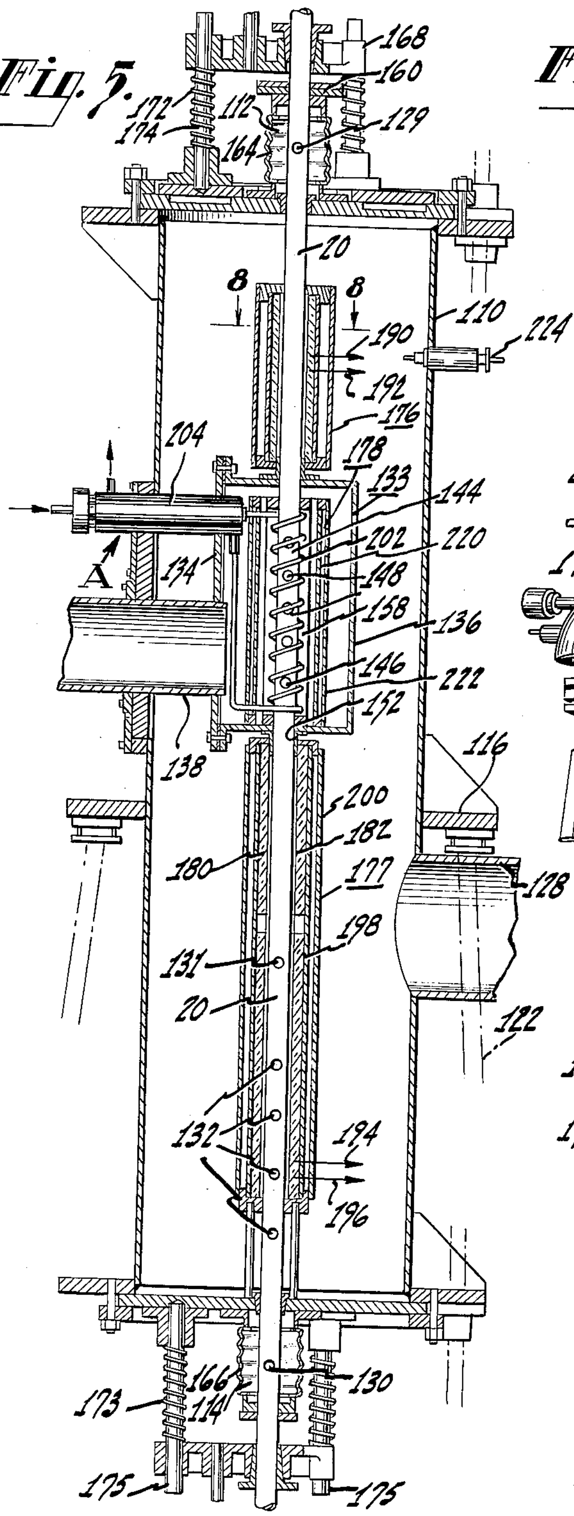
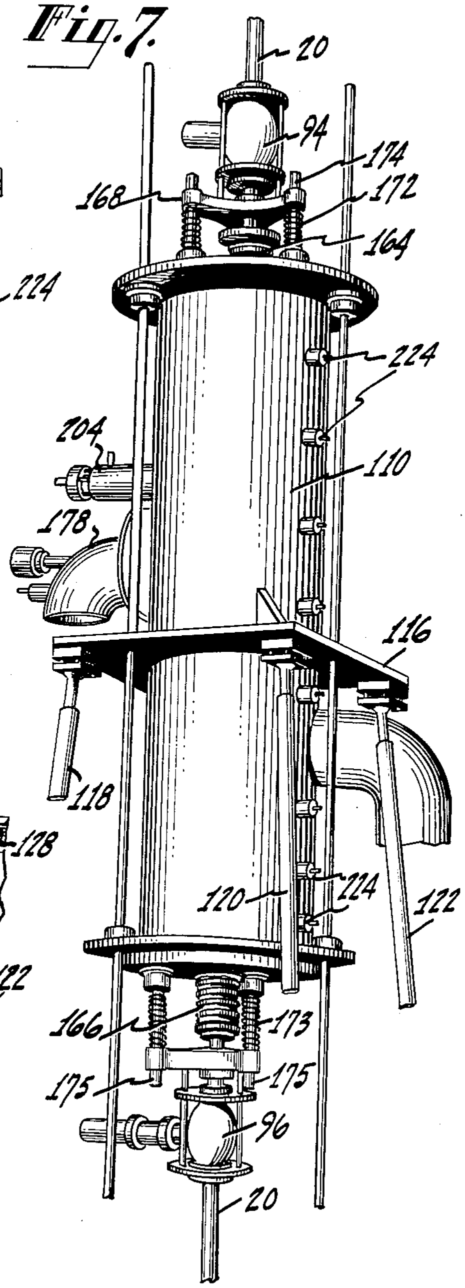
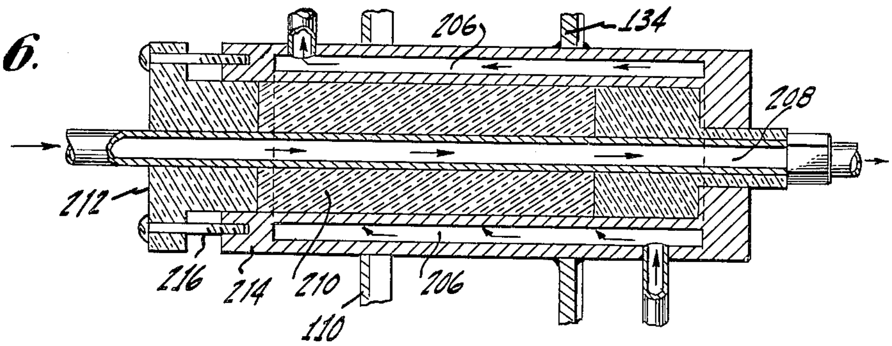


Fig. 7.



INVENTOR.
WILLIAM J. HELWIG
BY L. A. Larsen
ATTORNEY

Fig. 6.



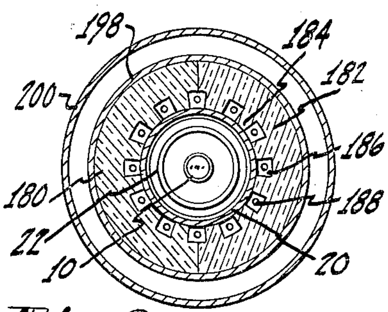


Fig. 8.

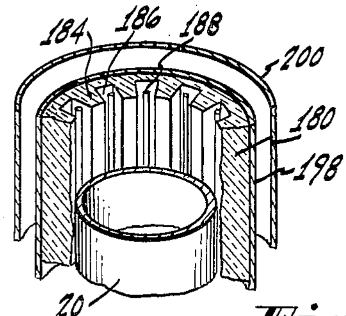


Fig. 9.

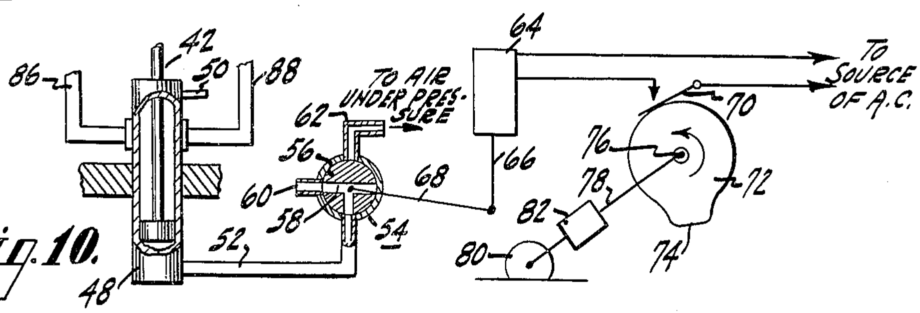


Fig. 10.

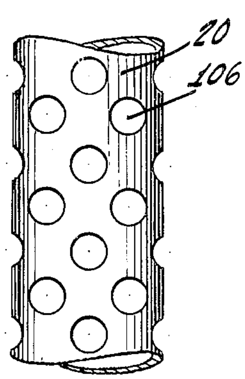


Fig. 11.

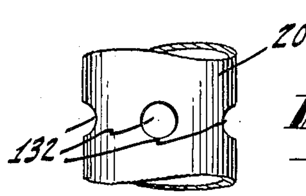


Fig. 12.

INVENTOR.
WILLIAM J. HELWIG
BY L. A. Larsen
ATTORNEY

United States Patent Office

3,057,130

Patented Oct. 9, 1962

1

3,057,130

APPARATUS FOR PROCESSING ARTICLES OR MATERIALS IN A CONTINUOUS FLOW OPERATION

William J. Helwig, Kearny, N.J., assignor to Radio Corporation of America, a corporation of Delaware

Filed Mar. 5, 1959, Ser. No. 800,357

20 Claims. (Cl. 53—86)

This invention relates to an apparatus for and method of processing articles, such as electron tubes, and in particular, is concerned with an improved method of and apparatus for heat treating and/or vacuum processing workpieces fed in a continuous flow.

While the invention will be described in an environment having utility in evacuating and sealing electron tubes, it is not limited to such utility. Indeed, an apparatus and method incorporating the invention has utility in a wide range of applications involving the vacuum and/or heat treatment of articles and materials in a continuous flow operation.

One type of apparatus employed on a relatively large scale for processing electron tubes to provide an evacuated and sealed envelope is known as a Sealex machine. This type of machine includes two turrets, on one of which a stem wafer is sealed to a bulb of an electron tube, and on the other of which the envelope formed by the stem and bulb is evacuated through an exhaust tubulation, and the tubulation is pinched off.

This type of apparatus is characterized by several objectionable features. One of such objectionable features resides in a discontinuity in the processing. Such discontinuity arises as a consequence of the need to transfer workpieces from one to the other of the aforementioned two turrets. Such transfer usually is effected manually and involves a time interval, during which the workpieces are removed from machine control. Not only does this time interval represent an undesirable time delay in tube manufacture, but it is accompanied by risks of tube damage incidental to tube handling and by the expense of operator attendance.

In addition to the aforementioned discontinuity in operation, Sealex machines are accompanied by the disadvantage that the evacuating operation is effected under conditions wherein the outer wall of the tube envelope undergoing evacuation is subjected to atmospheric pressure. Since the tube envelope is usually heated during the evacuating operation by heating means directed to driving out occluded gases from tube elements, the glass of the envelope is raised to a temperature that may be high enough to set strains therein, in response to stresses produced by the pressure differential on the outer and inner walls of the envelope. Such strains may produce cracks in the tube envelope, thereby destroying further utility of the tube. Furthermore, the pressure differential referred to produces objectionable suck-in of the portion of the exhaust tubulation softened for pinch-off.

In the evacuation and sealing of the envelopes of certain tube types provided with exhaust tubulations, the foregoing objectionable features of Sealex machines, in respect of discontinuity and pressure differential, have been tolerated in view of the relatively high speed of processing that such machines provide. However, certain other tube types having no exhaust tubulations in the envelopes thereof and requiring sealing of envelope parts after evacuation, cannot be processed by Sealex machines.

For processing such other tube types, use has been made of a bell jar type of enclosure within which the envelope parts of a tube are placed. While this type of processing avoids the pressure differential characteristic of Sealex machines in that the entire space within the bell jar enclosure is evacuated, thus equalizing the pressure on the inner and outer surfaces of the envelope parts, it is subject to a discontinuity of an even more serious kind than that associated with Sealex machines. Consequently, the bell jar type of processing device does not lend itself to efficient mass production of electron tubes.

2

Accordingly, it is an object of the invention to provide an improved method and apparatus for vacuum and/or heat processing workpieces in a continuous flow operation.

It is a further purpose to provide an evacuating and sealing apparatus which includes a structure defining a continuous flow path therethrough for articles, such as electron tube workpieces to be processed, and wherein the flow path has an ambient for avoiding objectionable suck-in of a softened seal region.

Another object is to provide a method of and apparatus for first evacuating a space defined by loosely positioned envelope parts and then sealing the parts, in an operation involving continuous travel of the parts in a predetermined path, for increasing the efficiency and speed of tube manufacture.

A further aim is to provide means defining a predetermined path of travel of tube envelope parts, wherein the path is characterized by a convex temperature profile extending from one end of the path to the other, for providing relatively low temperature at the path ends to facilitate loading and unloading parts at such ends, and a relatively high temperature at a region intermediate the ends of the path, for sealing said parts together.

Another purpose is to provide means defining a path having a convex temperature gradient and a concave gas pressure gradient therealong, for facilitating a continuous evacuating and sealing operation.

A further object is to provide an evacuating and sealing apparatus having a structure including a rectilinear tube and heating and evacuating means distributed along the length thereof to provide a temperature and degree of evacuation within the tube having a gradient rising from one end of the tube to an intermediate portion thereof, and falling from said intermediate portion to the other end of the tube, for facilitating not only a continuous processing of workpieces carried through said tube, from one end thereof to the other, but also the loading and unloading of the workpieces at the tube ends.

A further object is to provide an evacuating and sealing apparatus having path-determining means responsive in enlargement to increasing temperatures to provide increased access of said parts to an evacuating means at relatively high temperatures.

Another purpose is to provide a rectilinear tubular evacuating oven and a workpiece carrier made of such materials that the inner diameter of said oven is enlarged at a region of maximum temperature while the carrier is substantially free from enlargement transversely of the tube, to facilitate evacuation of a space defined by said carrier in the aforementioned region.

Another purpose is to provide an evacuating system wherein two or more evacuting means overlap in a region where the lowest gas pressure is desired.

Another aim of the invention is to provide an evacuating and sealing apparatus having a structure defining a rectilinear path therethrough, and including work carriers adapted to close effectively from the ambient atmosphere, regions of said path, for facilitating the evacuation of electron tube envelope workpieces carried through the aforementioned regions.

One embodiment of the invention selected for illustrative purposes only, comprises a structure including a vertically supported metal tube having a predetermined inner diameter and a plurality of aperture groups spaced axially thereof. The tube is embraced at regions including at least one aperture group by duct means communicating with an evacuating means. The two aperture groups adjacent to the opposite ends of the metal tube are each associated with an evacuating means having a capacity of gas conductance that is appreciable in relation to the gas conductance through open ends of the tube to the two aperture groups aforementioned. Several groups of apertures in an intermediate portion of the tube are connected to a third evacuating means of greater efficiency than the first named evacuating means. Thus, the latter evacuating means may comprise mechanical vacuum pumps, while the third means may constitute oil diffusion pumps backed up by mechanical pumps.

To further increase the efficiency of the evacuation of the intermediate portion of the tube in the embodiment referred to, a first chamber embracing several groups of apertures is connected to an oil diffusion pump backed up by a mechanical pump, while a second chamber within the first chamber embraces at least one group of apertures of said several groups and is connected to an independent oil diffusion pump backed up by a mechanical pump. In this way, the gas pressure differential within and outside of the inner chamber is reduced for increased efficiency of evacuation of the portion of the tube embraced by the inner chamber.

The foregoing combination of evacuating means provides a gas pressure gradient in the metal tube which is concave in profile, that is, the gas pressure in the portion of the tube embraced by the aforementioned inner chamber is lowest and increases toward both ends of the tube. In the embraced portion of the tube, therefore, maximum evacuation of an envelope defined by workpieces takes place, and accordingly, the parts are sealed in this portion to preserve the aforementioned maximum evacuation.

For heating the interior of the metal tube to provide predetermined heat zones for degassing, cathode activation and sealing, a system is provided having a moderate heating capacity in relation to the portion of the metal tube embraced by the outer evacuating chamber aforementioned, and excluding the portion embraced by the inner chamber, and an appreciably high heating capacity adjacent to the last named tube portion. The inner chamber is spaced along the axis of the metal tube from both ends of the outer chamber, and the outer chamber is disposed intermediate the tube ends. In this way, the temperature gradient, from one end of the metal tube to the other, is substantially convex in profile, so that an intermediate portion of the tube is at sealing temperature and the ends of the tube are relatively cool for convenient loading and unloading of workpieces.

To reduce gas conductance from the ends of the tube to the several pumping regions, a novel carrier for workpieces is provided having one or more spaced wafers of a diameter to provide a relatively small clearance fit with the inner wall of the metal tube adjacent to the cooler end portions thereof. In this way, when the metal tube is fully occupied by work carriers, interior portions along the length of the tube are appreciably blocked against passage of gas admitted from the external atmosphere.

An important feature of the invention resides in appropriate selection of materials for the metal tube and work carrier wafers, so that the metal tube may have an appreciable coefficient of expansion causing its inner diameter to enlarge at the hotter intermediate portion thereof, while the wafers do not enlarge appreciably. Thus, the annular spacing between the inner wall of the tube and the periphery of a wafer is enlarged at the intermediate portion of the tube where evacuation is most efficient. This enlarged space facilitates evacuation of envelope workpieces supported on the work carriers.

Work carriers of the type referred to may be loaded continuously in tandem relation into the lower end of the metal tube, either manually or mechanically, to assure a predetermined rate of travel of previously loaded carriers through the tube. This rate is related to the capacities of the evacuating means and heating means, and must be sufficiently slow to assure desired evacuation of envelope parts on the carriers and desired sealing of the parts after evacuation.

Carriers with evacuated and sealed electron tubes emerging from the upper end of the metal tube may be removed manually or mechanically.

Further features and advantages of the invention will become apparent as the present description of an embodiment thereof proceeds.

In the drawing, to which reference is now made for a consideration of an embodiment of the invention, by way of example,

FIG. 1 is an enlarged view in elevation, partly broken away, of envelope workpieces that may be processed by an apparatus according to the invention;

FIG. 2 is a partly sectional schematic elevational view of an apparatus embodying the invention;

FIG. 3 is an enlarged fragmentary view, partly in section, of the loading and retaining mechanism employed in association with the apparatus shown in FIG. 2;

FIG. 4 is an enlarged sectional view in elevation of a work carrier and baffle used in the operation of the apparatus shown in FIG. 2;

FIG. 5 is an enlarged sectional view in elevation of the structure of a portion of the apparatus depicted in FIG. 2;

FIG. 6 is an enlarged sectional view taken in the general direction of arrow A shown in FIG. 5;

FIG. 7 is a perspective structural view of the apparatus shown schematically in FIG. 2 with certain parts, shown in FIG. 2, omitted in the interests of clarity;

FIG. 8 is an enlarged sectional view taken along the line **8—8** of FIG. 5;

FIG. 9 is a fragmentary perspective view of a portion of the radiant heating means;

FIG. 10 is a schematic view of an actuating system that may be employed in connection with the loading mechanism shown in FIG. 3;

FIG. 11 shows an enlarged fragmentary elevation of a portion of the processing tube of the apparatus shown in FIGS. 2, 5 and 7, and depicts one of several similar sets of openings in the processing tube; and

FIG. 12 shows an enlarged fragmentary elevation of the processing tube and depicts another set of openings therein.

The workpieces to be processed by the apparatus of the invention may comprise a metal bulb **10** made of steel, for example, and an electron tube mount including a stem wafer **12**, made of a ceramic, such as forsterite, having lead wires **14** extending therethrough, as shown in FIG. 1. A ring **16** of brazing material made of an alloy, such as NIORO solder, known in the trade, is disposed adjacent to the periphery of the wafer **12**, and the end of the bulb **10**, closed by loosely positioning the wafer **12** thereon. The periphery of the wafer **12** may have a coating **18** thereon, made of molybdenum, for example.

A processing of the described workpieces by the apparatus, according to the invention, involves evacuating the envelope loosely defined by the wafer **12** and the bulb **10**, degassing metal components of the electron tube shown in FIG. 1, activating a cathode, not shown, incorporated in the electron tube aforementioned, and sealing the periphery of the wafer **12** to the inner wall of the bulb **10**.

When the bulb **10** and wafer **12** are in the loosely assembled position shown in FIG. 1, sufficient communication between the space defined by the bulb and wafer, and the exterior is provided, so that when the parts referred to are placed in an ambient of reduced gas pressure, the gas pressure within the space aforementioned is reduced correspondingly. Furthermore, in the position shown, a heating of the solder ring **16** to its melting point temperature, will cause the melted solder to flow downwardly between the periphery of the wafer **12** and the inner wall of the bulb **10**, to provide a hermetic seal therebetween when the solder is cooled to hardness.

For accomplishing the foregoing vacuum processing and heat treatment of the electron tube workpieces described, an apparatus is provided including a tube 20 defining a path of travel for the workpieces from one end of the tube to the other in a continuous flow, as shown in FIGS. 2, 5 and 7. The tube 20 is approximately ten feet long. The apparatus includes a plurality of combined carriers and baffles 22, one of which is shown in FIG. 4. Each carrier includes a cylindrical portion 24, having openings 26 and extending from one side of a baffle disc 28 defining two flanges or baffles 30 and 31, and a supporting recess 32, on which the electron tube workpieces shown in FIG. 1 are adapted to rest. The cylindrical portion 24 surrounds the workpieces, and the baffle disc 28 provides a cavity 33 into which the lead wires 14 of workpieces supported in a lower carrier may extend. A plurality of carriers are adapted to be received in tube 20 in tandem relation.

The carriers are preferably made of a material which exhibits a small heat retaining property. Thus, if the specific heat of the carriers is relatively small, the carriers will cool rapidly and assume substantially room temperature when unloaded from tube 20. When the composition of the carriers 22 is cold rolled steel and their structure is as shown in FIG. 4, their heat retaining property is sufficiently small to permit convenient unloading thereof, after passage through the heat zones to be described at a rate to be specified herein.

Work carriers 22 may be fed successively into the lower open end of tube 20, shown in FIG. 3, either manually or mechanically. The rate of feed should be such as to assure sufficient time for several processing elements disposed outside of and extending along the tube, to operate on the workpieces. In one example, to be described, this rate is one carrier per minute.

In the example shown in FIGS. 2, 5 and 7, the processing tube 20 is disposed in vertical position. Consequently, the combined weight of the carriers previously loaded into the tube will rest on the lowermost carrier. To support the column of carriers in tube 20, between loading operations, a stop structure is provided, as shown in FIG. 3, comprising a pin 34 urged by a spring 36 into distended position through the wall of tube 20 and into the path of travel of carriers therein. A head 38 on the pin determines its maximum distended position. The portion of the pin 34 extending into the tube 20 is bevelled on its lower side, so that a forceful extension of a carrier 22 into the lower open end 40 of the tube will cause the flange 30 on the carrier to bear against the bevelled side of pin 34, thereby causing the pin to retract against spring 36 and permitting the flange 30 to pass upwardly beyond the pin. As soon as the flange 30 clears the pin 34, the pin is free to spring out to distended position, for engaging the underside of flange 30 and restraining falling movement at the carrier 22.

While it is feasible to feed work carriers manually into the lower end portion 40 of the processing tube 20 at the required rate, it is preferable to utilize mechanical means for this purpose, in view of the appreciable weight of the column of work carriers within tube 20, and which requires lifting manually in a manual feed. A suitable mechanical system 37 (FIG. 2) for feeding carriers into the lower end of tube 20 is shown in FIGS. 3 and 10. The system may include a piston 42 having an enlarged head portion 44 extending through an opening in a table 46 fixed as by welding to the lower end of processing tube 20. The piston 42 extends into a pneumatic cylinder 48 having an upper duct 50 communicating with the atmosphere, and a lower duct 52 communicating with a source of air under pressure, not shown, through a three-way valve 54. The valve 54 includes a valve member 56 having a T-shaped channel 58 and shown in a position wherein the channel provides communication between duct 52 and a duct 60 communicating with the atmosphere. Rotation of the valve member 56 in a counterclockwise direction, as viewed in FIG. 10, and through an arc of 90°, will permit communication only between duct 52 and a duct 62 connected to the aforementioned source of air under pressure.

To actuate the valve member 56 successively to the two positions referred to, a solenoid 64 includes a piston 66 pivotally linked to an arm 68 connected to the valve member. The solenoid has a structure for normally disposing the piston 66 in extended position. In this position the upper surface of the piston head 44 (FIG. 3) is flush with the upper surface of table 46. However, when the solenoid is connected to a source of A.C. electrical energy, it retracts piston 66, thereby actuating the valve member 56 to a position wherein the channel therein communicates with ducts 52 and 62 and the source of air under pressure. This causes the piston 42 and the piston head 44 to rise through table 46 for pushing a work carrier loaded on the upper surface of the piston head, up into tube 20 and to a position wherein the flange 30 on the carrier is above pin 34 for preventing return downward movement of the loaded carrier on subsequent retraction of the piston 42 and head 44.

For controlling the feed of work carriers into the tube 20, at a rate of say one carrier per minute, a switching arrangement (FIG. 10) is provided across the A.C. power line serving the solenoid 64. This switching arrangement includes a switch 70, normally open, and adapted to be closed by a cam 72 having a switch closing lobe 74. The cam is rotated counterclockwise, as viewed in FIG. 10, on an axis 76 by a shaft 78 engaging the cam connected to a motor 80 through a gear box 82, to provide a rate of one rotation through 360° per minute.

The lower end portion 40 of processing tube 20 has a portion of its wall removed, as shown at 84, 85 (FIG. 3). The removed portion includes an arc of at least 180° to allow a carrier 22 to be inserted therein in coaxial and operating relation with respect to the tube 20. The inserting operation is facilitated by the fact that the upper surface of cylinder head 44 is flush with the upper surface of table 46 between intermittent loading movements of the piston head. This facility in the inserting operation renders the use of manual means feasible. However, mechanical means, not shown, may be used for inserting work carriers into the lower end of the processing tube.

For a reason that will become apparent, the cylinder 48 is preferably supported by table 46, by means of suitable brackets 86, 88, as shown in FIGS. 3 and 10. As has previously been mentioned, the table, in turn, is supportingly fixed to the lower end of the tube 20. As a consequence, axial expansions of the tube 20 will not effect the flush position of the piston head 44 with respect to the upper surface of table 46, which is important in facilitating loading of carriers into the tube.

As the work carriers 22 are raised in tube 20, the uppermost carrier in the column will emerge from the upper end of the tube. The emerging work carrier may be removed either manually or by mechanical means, not shown.

For suitably vacuum treating, the workpiece in the work carriers 22, as the carriers travel through the processing tube 20, suitable means are provided for producing a gas pressure gradient within tube 20 that is concave in profile along the tube. That is to say, the gas pressure at the open ends of the tube 20 is atmospheric and decreases toward an intermediate portion of the tube 20, at which the pressure is sufficiently reduced for providing a desired ambient having a degree of evacuation required in the envelopes of the electron tube workpieces.

The means for providing the aforementioned gradient in gas pressure comprises a system for producing zones surrounding axially spaced portions of the tube 20, each having a desired pressure to produce the gradient referred to. The wall of the tube 20 is provided with openings at each zone for equalizing the gas pressure within each zone and the interior of the adjacent tube portion. Adjacent the intermediate portion of the tube 20, two overlapping zones are provided for maximum evacuation of this portion.

Reference to FIGS. 2 and 5 reveals one specific form that the aforementioned pressure reducing means may assume. As shown in FIG. 2, two mechanical vacuum pumps 90, 92 are connected to fittings 94, 96 embracing portions of the tube 20 adjacent to its ends and defining chambers or tanks 98, 100, respectively. The vacuum pumps referred to may be of the type known commercially as Kinney KDH65. Two sets of openings 102, 104 in the wall of tube 20 provide communication between the chambers 98, 100, respectively, and the interior of the adjacent portions of the tube.

Each set of openings 102, 104 comprises twenty-eight openings 106 extending along the tube 20 a distance of about one and one-half inches, as shown in FIG. 11. Each opening is about one quarter inch in diameter, and each set includes seven annular arrays of four openings each, the openings in each array being equidistantly spaced around the tube 20. Adjacent arrays are staggered circumferentially of the tube 20 to permit a grouping of the twenty-eight openings in a one and one-half inch length of the tube without appreciably weakening the tube, and for desired air flow conductance between the chambers 98, 100 and the interior of the adjacent portions of tube 20.

Pumps 90, 92 produce a degree of evacuation of chambers 98 and 100, and the interior of adjacent portions of the tube 20, that is dependent on several factors. These factors constitute the capacity of the pumps, the air flow conductance between the ends of the tube 20 and through the sets of openings 102, 104 referred to, and the degree of blockage to such flow presented by the work carriers 22.

With the capacity of the aforementioned pumps known, the air flow conductance and the degree of blockage to flow may be controlled to provide a gas pressure in chambers 98, 100 and the adjacent interior regions of the tube 20, that is less than 10 mm. of mercury, and about 6 mm. of mercury. Thus, it has been found by applicant that a desired control of air flow conductance is realized when tube 20 is provided with an inner diameter of 1.055 inches, when the portions of tube 20 having the sets of openings 102, 104 are spaced approximately twenty inches from the adjacent ends of the tube, and when the clearance between the inner wall of the tube and the periphery of flange 30 on work carriers filling the tube is about 0.003 inch when cold. The gas pressure referred to is, of course, also dependent on the gas pressure in the portion of the tube 20 intermediate the chambers 98, 100.

For reducing the gas pressure in a relatively long intermediate portion of tube 20, a relatively large diameter chamber or tank 110 is provided which embraces the intermediate portion aforementioned, as shown in FIGS. 2 and 5. The tank 110 is cylindrical in shape and about four feet long and has a diameter of about one foot. End portions of the tank are hermetically sealed around the tube 20 by means of bellows 112, 114. The tank is supported by a bracket 116 resting on four legs, three of which 118, 120 and 122, are shown in FIG. 7. The tank 110 serves the two functions of providing a low gas pressure ambient about the aforementioned intermediate portion of tube 20, and of supporting tube 20.

For providing the low gas pressure ambient referred to, which is approximately 0.0002 mm. of mercury, the tank 110 is connected to an oil diffusion pump 124 backed up by a mechanical pump 126, by means of a high conductance duct 128, as shown in FIG. 2. The oil diffusion pump has a capacity of 500 liters per second, and may be of a commercially available type known by the designation CEC–MC500B. The mechanical back-up pump used, has a capacity of sixty-five cubic feet per minute, and is known commercially by the designation Kinney KDH65.

For providing communication between the low gas pressure ambient produced in tank 110, and the interior of the tube portion embraced by the tank, a plurality of sets of openings are provided in the wall of tube 20. One of two sets of openings shown schematically at 129, 130 in FIGS. 2, and of the type shown in FIG. 11 and comprising twenty-eight openings each, is disposed in the wall of each portion of the tube 20 located within the space defined by each of bellows 112, 114. Each set is spaced about thirty-five inches from the adjacent end of tube 20. An additional set of openings 131, also similar to the set shown in FIG. 11, is spaced inwardly of tank 110 from opening set 129, a distance of about one foot. Further sets of openings 132, each comprising four openings spaced around tube 20, as shown in FIG. 12, each having a diameter of one quarter inch, are distributed between opening sets 130 and 131. The opening sets 132 are spaced about one and one-half inches from each other and from sets 130, 131 axially of tube 20.

This arrangement of openings in the wall of tube 20 assures a reasonably constant pressure within tank 110 of about 0.0002 mm. of mercury, even though workpieces located within the region of the tube 20 encompassed by the tank 110, may be releasing considerable quantities of gas.

However, the gas pressure in tank 110, and the interior portions of tube 20 to which communication is afforded by opening sets 129, 130, 131 and 132 aforementioned, is not sufficiently low to provide a desired evacuation of workpieces being processed. Therefore, a second tank 133 is disposed within tank 110, and embraces a length of tube 20 having an axial extent of about one foot. The second tank, or inner vacuum chamber 133 is semi-cylindrical in shape and includes a flat side 134 removably fixed to the semi-cylindrical portion 136. The flat side referred to is fixedly supported on an air duct 138, which extends through and is hermetically sealed to the wall of the larger tank 110.

For evacuating the interior of the vacuum chamber 133 to a gas pressure of about 0.00001 mm. of mercury, the duct 138 is connected to an oil diffusion pump 140 backed up by a mechanical pump 142. The oil diffusion pump 140 has a capacity of three hundred liters per second and is of a type known commercially by the designation CEC–MCF300. The mechanical back-up pump is of a type available commercially under the designation Kinney KS13.

To provide communication between the vacuum chamber 133 and the interior of the portion of tube 20 which it surrounds, two sets of perforations 144, 146 of the type shown in FIG. 11 are provided through the wall of the tube portion referred to. These two sets of perforations are spaced about nine inches from each other, axially of tube 20. Intermediate perforation sets 144, 146, are provided three sets of openings 148 of the type shown in FIG. 12. The opening sets 148 are spaced about one and one-half inches from each other axially of tube 20. These five sets of openings in the tube portion embraced by the inner vacuum chamber 133 effectively eliminate any appreciable pressure differential between the vacuum chamber and the space within the tube portion referred to. Thus, the pressure in this space is maintained reasonably constant at 0.00001 mm. of mercury, even though workpieces processed in the space evolve an appreciable quantity of gas.

It will be appreciated from the foregoing that the pressure differential between the interior of tanks 110 and 133 is appreciable. To preserve this pressure differential and yet allow expansive movements between the inner tank 133 and the tube 20, the inner tank is provided with sleeves 150, 152, which are hermetically sealed to end portions of tank 133 and embrace the tube 20 in snug and yet movable engagements. To this end the clearance between the sleeves 150, 152 and the tube 20 is about 0.003 inch radially.

It will be appreciated further from the foregoing that the gas pressure zones in chambers 98, 100, 110 and 133 communicating with the interior of the tube 20, produce a gas pressure gradient within tube 20 that is concave in profile along the tube. Thus, at the ends of the tube, the gas pressure is atmospheric. From the ends of the tube, regions of progressively reduced gas pressure are provided, until at the intermediate portion of the tube embraced by vacuum chamber 133, a gas pressure of about 0.00001 mm. of mercury is realized. This pressure gradient is obtained without closing the ends of the tube 20. While the work carriers 22 effect partial closure of the end portions of the tube, sufficient clearance between the sides of the carriers and the inner wall of the tube is found necessary for free travel of the work carriers through the tube. This clearance, while exposing the interior of the tube 20 to atmospheric pressure, is insufficient, according to the invention, to prevent the high degree of evacuation secured in an intermediate portion of the tube.

As has been indicated previously herein, the tank 110 not only serves to produce a zone of desired low gas pressure, but also provides support for the processing tube 20. The tank 110 is well suited to serve a support function, since it is ruggedly supported on bracket 116, as previously described.

The tube 20 is supported at end portions of tank 110 by means of the bellows 112, 114 previously referred to. The bellows include sleeves 160, 162 which fixedly engage the outer surface of the tube 20. The corrugated cylindrical bellows bodies 164, 166 are fixed at one end thereof, as by brazing or welding, to the peripheries of sleeves 160, 162. The other ends of the cylindrical bellows are fixed suitably to edges defining openings in the end walls of tank 110, as by brazing or welding. The bellows bodies may be made of a material, such as stainless steel, and the thickness of the side walls of the bodies 164, 166 may be from twenty to thirty mils, if the bellows alone are relied upon to support the tank 110.

In addition to suporting the tank 110, the bellows 112, 114 exert a tensile force on the portion of tube 20 extending therebetween. This tension is desirable to prevent buckling or other deformation of tube 20 in response to relatively high processing temperatures.

If desired, the supporting function of the bellows 112, 114 may be supplemented by an additional structure. This additional structure includes three-armed spiders 168, 170 fixedly clamped around portions of tube 20 spaced from the bellows referred to. Compression springs 172, 173 bear against the outer surfaces of the end walls of tank 110 and the arms of the two spiders aforementioned. The springs are guided by rods 174, 175 which are freely movable through the spider arms. If this additional support and tensioning structure is used, the material of the bellows bodies may have a reduced thickness of ten mils, for example.

In addition to providing an evacuated ambient for evacuating the enclosure formed by envelope workpieces, it is also desirable to heat the workpieces first to degas the material of the workpieces and activate a cathode included within the envelope workpieces, and finally to seal the envelope workpieces to preserve the evacuated space therein. To this end a heating system is provided adapted to produce a temperature gradient along the tube 20 that is substantially convex in profile. This assures that the workpieces are gradually raised to a sealing temperature through a gradient at which outgassing and cathode activation take place prior to sealing, and which gradually is reduced to room temperature to avoid objectionable strains in the workpieces.

The heating system referred to includes radiant heat producing structures 176, 177 spaced along the tube 20 within tank 110, and a radio frequency heating structure 178 positioned between the radiant heating structures 176, 177. Each of heat radiating structures comprises two semi-cylindrically insulating members 180, 182 made of an insulating material, such as Alundum, as shown in FIGS. 5, 8 and 9. The insulating members 180, 182 have inwardly extending ribs 184, defining a plurality of elongated recesses 186 extending longitudinally of tube 20. A wire 188 made of a high electrical resistance material, such as Nichrome, is disposed in the recesses. The ends of the resistance wire 188 in heating structure 176 are connected to a suitable source of electrical power, not shown, through leads 190, 192, and the wire 188 in heating structure 177 is also connected to a suitable source of electrical power through leads 194, 196.

Each of the radiant heating structures 176, 177, also includes two concentric and radially spaced heat reflecting cylinders 198, 200 made of a highly heat reflecting material, such as stainless steel.

The temperature produced within tube 20 by the radiant heating structures 176, 177 energized by a sixty cycle commercial current, is about 800° C. This temperature appears in a region relatively close to the ends of the inner vacuum chamber 133 and decreases towards the remote ends of the heating structures aforementioned. This gradient is produced partly as a consequence of heat generated by the radio frequency heating structure 178 surrounding a portion of tube 20 intermediate the radiant heating structures 176, 177.

The radio frequency heating structure 178 comprises a tubular coil 202, made of an electrically conductive material, such as copper, embracing a portion of tube 20, including opening sets 144, 146 and 148 in the tube wall, in suitable spaced relation to the tube. The ends of the coil 202 pass therough the flat side 134 of the vacuum chamber 133, and through the side wall of tank 110, by means of radio frequency energy feed-through connection 204, shown in FIGS. 5 and 6. This feed-through connection, as shown in FIG. 6, includes coaxial ducts 206, 208, made of electrically conductive material, such as copper and supported by a body of compressible insulating material 210. The material 210 is compressed in the annular space between ducts 206 and 208 by a plug 212 of insulating material, fixed to the body 214 defining duct 206, by two screws 216. The feed-through connector referred to, is hermetically sealed through the walls of the tanks 110 and 133 by engagements involving contacts between the tanks and the outer duct member 206. This duct member is operated at RF ground, not only to permit direct contact with the tanks 110 and 133, but to avoid objectionable reactance effects with the tanks aforementioned.

Inner duct 208 is connected to an RF source 217 having frequency of about four hundred kilocycles and a power output of about two kilowatts.

The coaxial ducts 206 and 208, and the coil 202 are hollow, to allow a cooling fluid from a source 217 to flow therethrough.

It is desirable that the magnetic flux produced by the coil 202 penetrate to the interior of the adjacent region of processing tube 20. To this end, desirable flux communication to the interior of the tube 20 is provided, not only by opening sets 144, 146 and 148 in the tube wall, but also as a consequence of the non-magnetic material of which the tube is made, and the thinness of the tube wall. Thus, the tube 20 is made of a non-magnetic material, such as an alloy known in the trade as Inconel, and the wall thickness of the tube is about 0.035 inch. This composition of tube 20, the thinness of the wall thereof, and the openings 144, 146 and 148, allow the RF flux produced by coil 202 to extend into the interior of tube 20, and through openings 26 in the work carriers therein, for heating the workpieces by RF energy induced therein. The RF coil is adapted to produce an ambient in which the workpieces are raised to a temperature of about 950° C.

To confine the heat produced by coil 202 to a region relatively close to the tube 20 and remote from the walls of the vacuum chamber 133. two concentric and radially spaced heat shields 220, 222 are disposed in spaced relation around the coil 202. The shields referred to are made of a material having a high heat reflecting property, such as stainless steel.

It is preferable to employ an RF coil for heating the ambient of maximum evacuation, since the coil includes a relatively small mass that is more readily degassed than the radiant heating structures before referred to.

The material of the tube 20 and the composition of the work carrier 22 are such as to permit appreciable radial expansion of the tube at the hottest region thereof, at which maximum evacuation of the workpieces is desired, while the carrier is free from appreciable radial expansion. This desirable result is obtained when the tube 20 is made of Inconel, as previously mentioned, and when the carrier is made of cold rolled steel.

The unequal expansions of the tube 20 and the carrier 22, referred to, enlarge the space between the inner wall of tube 20 and the peripheries of the flanges 30, 31 of the carrier 22. This is desirable in that it reduces resistance to conduction of gas from a region between two carriers when such region is between two sets of openings in the tube wall. This reduction in flow resistance contributes to increased efficiency of the evacuating means at the region of the tube 20 where maximum efficiency is desired.

However, the increase in the radial spacing produced between the inner wall of the tube 20 and the carrier 22 places a burden on the flanges 30, 31 to prevent tilting of the carriers in the tube. This burden is successfully met by the axial displacement of the two flanges referred to.

An important advantage of the processing apparatus described, is that it avoids suck-in of the sealing ring 16 when heated to melting temperature. This advantage occurs from the fact that the NIORO solder ring 16 is raised to melting temperature only in the region of tube 20 encompassed by the vacuum chamber 133. The ring is cooled to hardness while in the portion of tube 20 surrounded by the radiant heating structure 176, which is a region surrounded by tank 110, and in which the degree of evacuation is sufficiently high to avoid suck-in of the solder material prior to its hardening.

It is preferable to commence operation of the apparatus with the tube full of carriers 22, preferably empty of workpieces. The presence of carriers throughout the tube will result in a partial closure of end portions of the tube to the atmosphere, and improve efficiency of operation.

Before the first carrier with a workpiece is loaded, however, it is desirable to assure that the several zones along the tube 20 are heated to a specified temperature pointed out previously herein. This determination is made by inspecting the several thermocouples 224, shown in FIG. 7, and extending from the several heat zones along the tube 20 within tanks 110 and 133, to the exterior of tank 110. Suitable gauges, not shown, are also connected to the several zones along the tube 20, to provide an indication of the gas pressures therein, and should be examined before and during the operation of the apparatus, to assure that the gas pressures comply with the specifications set forth in the foregoing.

When operation of the apparatus is stopped, it is important that no workpieces remain in the tube 20. This is because such remaining workpieces will be only partially processed on resumed operation of the apparatus. The effects of initial processing of workpieces remaining in the tube after stoppage of the apparatus will be lost. To meet this problem, it is desirable to load a sufficient number of empty carriers 22 into tube 20 prior to stoppage of the apparatus, to allow all carriers having workpieces therein, to be unloaded before operation of the apparatus is stopped. This expedient is also of advantage, in that the tube 20 will be full of work carriers, when operation is resumed, for improved efficiency of operation, as aforementioned.

What is claimed is:

1. Apparatus for vacuum processing workpieces comprising a tube having inner walls defining a predetermined path, a work carrier movable in said path, first means connected to end portions of said tube for producing a first relatively low gas pressure within said end portions, second means connected to spaced portions of said tube intermediate said end portions for producing a second gas pressure lower than said first gas pressure in said spaced portions, and third means connected to the portion of said tube intermediate said spaced portions for producing a third gas pressure in said portion lower than said second pressure, whereby a gas pressure gradient is produced within said tube having a concave profile to facilitate loading said workpieces into one end of said tube and unloading thereof from the other end, said work carrier having transverse dimensions to dispose the sides thereof in relatively close spaced relation to said inner walls for effectively non-hermetically sealing at least one end portion of said tube from the ambient atmosphere.

2. Apparatus according to claim 1, and wherein, said third means comprises a first chamber surrounding said portion of the tube and communicating with the interior of said tube, and said second means comprises a second chamber surrounding said first chamber and said spaced portions of said tube and communicating with said spaced portions, whereby the gas pressure differential between the inside and outside of said first chamber is reduced, for efficient evacuation of said portion of the tube.

3. Apparatus for vacuum and heat treating a workpiece, comprising a tube made of a material having a predetermined coefficient of expansion and having inner walls defining a path, a work carrier movable in said path and having transverse dimensions to provide a relatively small clearance between the sides thereof and said inner walls required for free movement of said carrier in said path when said tube is at room temperature, said tube having a uniform diameter throughout its length when at room temperature, means for evacuating an intermediate portion of said tube, and means for heating said intermediate portion to a temperature higher than room temperature, whereby said inner walls at said intermediate portion expand radially a predetermined amount, said carrier being made of a material having a smaller coefficient of expansion than the material of said tube, whereby said carrier, when in said intermediate portion, expands laterally a smaller amount than said predetermined amount, for enlarging said clearance and providing a desired path for uniform evacuation of regions adjacent to opposite ends of said carrier.

4. Apparatus for evacuating a space defined by envelope parts and sealing engaging surface portions of said parts by means of a sealing alloy having a softening response to a predetermined high temperature and a hardening response to a predetermined low temperature, said apparatus comprising a tube having inner walls defining a predetermined path, a work carrier adapted to support said parts and movable in said path in a predetermined direction, first means adjacent to and communicating with an intermediate portion of said tube, for producing a first zone having a relatively low gas pressure for evacuating said space and having said predetermined high temperature for softening said alloy, and second means embracing another portion of said tube adjacent to said first zone and extending away from said first zone in said direction for providing a second zone having a temperature gradient from said predetermined high to said predetermined low temperatures and a gas pressure gradient from said relatively low pressure to another and higher gas pressure having a magnitude insufficient to produce damage by a pressure differential between said space and said second zone to a seal formed in said first zone.

5. Apparatus according to claim 4, and wherein said

embracing means provides a falling temperature gradient along said another portion of the tube, so related to a rising gas pressure gradient in said second zone, as to avoid an appreciable pressure differential between said space and said second zone prior to the hardening of said alloy.

6. Apparatus according to claim 4, and wherein said first means comprises a first tank defining an enclosure around said first zone only and communicating with the interior of said tube, an evacuating device connected to said tank for reducing the gas pressure therein to said relatively low pressure, and a radio frequency induction heating element adjacent to said tube and providing a flux penetrating the wall of said tube for heating said envelope parts to said predetermined high temperature; and said second means comprises a second tank defining an enclosure around said first tank and around said second zone, a heating element within said second tank and outside of said first tank and adjacent to a portion of said tube in said second zone for providing a temperature gradient in said second zone from the temperature in the adjacent portion of said first zone to said predetermined low temperature, and an evacuating device connected to said second tank for reducing the gas pressure therein to provide a pressure therein only slightly higher than the pressure in said first tank, said second tank communicating with the interior of said tube at a portion thereof spaced from said first zone, whereby a relatively small pressure gradient is provided in said second zone for avoiding a harmful pressure differential between said space defined by said envelope parts and the ambient in second zone while said sealing alloy is soft.

7. Apparatus for heat treating workpieces comprising a rectilinear metallic tube, an elongated housing encircling an intermediate portion of said tube and communicating with the interior thereof, means within said housing and adjacent to said intermediate tube portion for heating the same to an appreciably higher temperature than the walls of said housing, said tube and said walls being made of materials having substantially the same coefficient of expansion, whereby the portion of said tube within said housing expands longitudinally through a greater distance than the walls of said housing, the wall of said tube being thin in relation to the walls of said housing, and resilient means fixed to opposite ends of said housing and to portions of said tube outside of said housing, for tensioning said intermediate tube portion to prevent deformation thereof in response to said longitudinal expansion.

8. Apparatus for heat treating workpieces comprising a rectilinear tube having inner walls defining a path for said workpieces, a housing having side walls encircling an intermediate portion of said tube, a heating member within said housing for heating said intermediate portion of said tube and the path portion defined thereby to a predetermined temperature, said tube being freely movable through opposite end walls of said housing, said side walls and said tube being made of materials having coefficient of expansion to produce elongation of said intermediate tube portion in response to said predetermined temperature while said side walls are substantially free from elongation, and means connected to portions of said tube extending from said opposite end walls and to said end walls, for applying a tensile force on said intermediate tube portion to preserve said intermediate tube portion from heat induced deformation.

9. A processing apparatus comprising rectilinear inner and outer concentric tubular members, means for heating the inner member to a predetermined temperature, while maintaining the outer member at a lower temperature than said predetermined temperature, said members being made of materials having coefficients of expansion of such relative magnitudes as to cause said inner member to expand appreciably axially at said predetermined temperature while said outer member is free from appreciable axial expansion at said lower temperature, said inner member having portions extending from opposite ends of said outer member, and tension means supported on said outer member and engaging said portions and having a tensional force at least equal to the force tending to deform said inner member at said predetermined temperature.

10. A processing apparatus comprising three coaxial tubular members, the innermost of said member being concentric with portions only of the two outermost members, the intermediate member being concentric with a portion only of each of the outermost and innermost members, said intermediate member being fixed to the outermost member and engaging said innermost member in freely slidable relation, means within said intermediate member for heating said innermost member to a temperature at which said innermost member expands appreciably axially with respect to said intermediate member, and resilient tensioning means connected between said outermost member and portions of said innermost member extending beyond said outermost member, for providing a tensional force on said inner member to preserve said inner member from buckling at said temperature.

11. A processing apparatus according to claim 10, and wherein said outermost member is fixedly supported and resiliently joined to said innermost member, to allow relative axial movements of said outermost and innermost members.

12. Apparatus for vacuum processing and heat treating workpieces, comprising a metal tube having a wall defining a processing path therewithin, said wall having two groups of apertures spaced axially thereof a predetermined distance, a plurality of work carriers positioned in tandem relation and movable through said path in a predetermined direction, each of said carriers having a radially extending annular portion intermediate its ends, said annular portion having a diameter for snug yet free passage of said carriers in said path, said annular portions on two adjacent ones of said carriers in said tandem relation being spaced less than said predetermined distance axially of said tube, whereby adjacent end portions of said two carriers between the two annular portions thereof are between said apertures during travel of said carrier in said path, said end portions having walls defining a workpiece accommodating space, said space communicating with the ambient of said path, only at a region thereof intermediate said two annular portions, said wall of said tube being made of a material having a larger coefficient of expansion than the material of said carrier, means for heating said wall between said apertures to a temperature to cause said wall to expand radially, and means communicating with said two apertures for evacuating the ambient of said path, whereby said expansion of said tube all provides a desired path from each of said apertures to said workpiece accommodating space, for continuous evacuation of said last-named space during travel of said carriers between and past said apertures.

13. Apparatus for vacuum processing and heat treating workpieces comprising duct means having a wall defining a processing path, evacuating means adjacent to said duct means, said wall having an aperture to provide communication between said evacuating means and said path, a plurality of work carriers in tandem relation movable in said path, two adjacent work carriers having a structure defining a work holding space and two annular projections on opposite ends of said space providing a relatively small clearance with respect to said wall when at room temperature, said two work carriers providing communication between the ambient of said path and said work holding space, only at a region thereof intermediate said projections, whereby said space is substantially blocked from communication with said aperture when said wall is at room temperature and when said region is out of register with said aperture, and means for heating said wall, including the portion thereof having said aperture,

to a predetermined temperature, the material of said wall having a coefficient of expansion that is larger than that of the material of said carriers, whereby said wall expands appreciably radially at said temperature to a magnitude greater than the expansion of said carriers, and a space is provided between said wall and projections communicating with the ambient of said path adjacent to said aperture and said workholding space for continuously evacuating said work holding space as said work carriers are moved in said path.

14. In a processing apparatus for electron tubes, a carrier comprising a disc, a tubular spacing element having one end engaging one face of said disc, the outer wall of said spacing element being spaced inwardly of the periphery of said disc, said disc having a recess extending from said one face adapted to receive a portion of a loosely assembled electron tube, said spacing element being adapted to receive another portion of said electron tube, said spacing element having apertures in the wall thereof, whereby said disc is adapted to space said wall inwardly of a path coaxial with said carrier, for providing communication between the ambient of said path and the interior of said carrier.

15. In a processing apparatus for electron tubes according to claim 14, and wherein said disc of said carrier has an axial length for preventing tilting of said carrier in said path.

16. A processing apparatus comprising a vertically disposed tube having a predetermined inner diameter and a plurality of work carriers movable in tandem relation from the lower end to the upper end of said tube, each of said work carriers comprising a disc member having an annular seat on one face of said disc member and spaced from the periphery of the disc, and a sleeve of a smaller outer diameter than the diameter of said disc member seated in said seat, said disc having another annular seat on the opposite face thereof of the same diameter as the first-named seat and adapted to receive an end of a second sleeve of the same outer diameter as the first-named sleeve, said disc member having an axial length and an outer diameter to prevent tilting of said carrier to a magnitude to cause said sleeves to contact said tube when said carrier is moved through said tube.

17. A processing apparatus comprising an elongated tube open at one end, means connected to said tube for providing zones of progressively lower gas pressure extending from an open end thereof and a work carrier movable in said tube from said open end to the region therein of lowest gas pressure, said work carrier having transverse dimensions for effectively closing the ambient within said tube and in advance of said carrier from said open end for preserving said lowest gas pressure in said tube.

18. A processing apparatus comprising an elongated tube having a zone of reduced gas pressure therewithin spaced from an open end of the tube, means for heating said tube at said zone to predetermined temperature, said tube being made of a material which responds in appreciable expansion to said temperature whereby the inner diameter of said tube is enlarged at said temperature, a work carrier comprising a disc portion adapted to support a workpiece and a cylindrical portion seated on said disc portion and adapted to provide a space between two work carriers in tandem relation for said workpieces, said disc being made of a material having a smaller expansion response to said temperature than said tube and means for feeding said work carrier through said tube from said open end thereof, said disc portion extending radially outward from said cylindrical portion and having transverse dimensions for snug receipt in said open end at room temperature, whereby said work carrier successively closes said open end when fed thereto, for isolating said reduced pressure zone from atmospheric pressure, and opens a path between the periphery of said disc portion and the inner wall of said tube at said zone, for improved efficiency of evacuation of said workpiece.

19. Apparatus for vacuum processing and heat treating work pieces including an elongated tubular member comprising means for heating the interior of said elongated tubular member for heat treating a work piece, a second tubular member surrounding said elongated tubular member, said second tubular member serving as a heat shield for said elongated tubular member, a third tubular member surrounding said elongated tubular member and said second tubular member and sealed vacuum tight to said elongated tubular member and providing a vacuum chamber around said elongated tubular member and said second tubular member, and means for evacuating said elongated tubular member and said third tubular member, said apparatus being adapted to receive a work piece carrier for moving a work piece into and out of said elongated tubular member for processing.

20. Apparatus for vacuum processing and heat treating work pieces including a first tubular member comprising means for heating the interior of said first tubular member for heat treating a work piece, a second tubular member surrounding said first tubular member, said second tubular member serving as a heat shield and reflector for said first tubular member, a third tubular member surrounding said first tubular member and said second tubular member and sealed vacuum tight to said first tubular member and providing a vacuum chamber around said first tubular member and said second tubular member, said apparatus having means for evacuating said first tubular member and said third tubular member and for providing communication between the first and third tubular members, said apparatus being adapted to receive a work piece carrier for moving a work piece into and out of said first tubular member for processing.

References Cited in the file of this patent

UNITED STATES PATENTS

2,710,713	Slater	June 14, 1955
2,787,101	Randels et al.	Apr. 2, 1957
2,857,723	Diehl et al.	Oct. 28, 1958
2,870,586	Pearson et al.	Jan. 27, 1959
2,889,670	Koch	June 9, 1959
2,918,763	Doran	Dec. 29, 1959