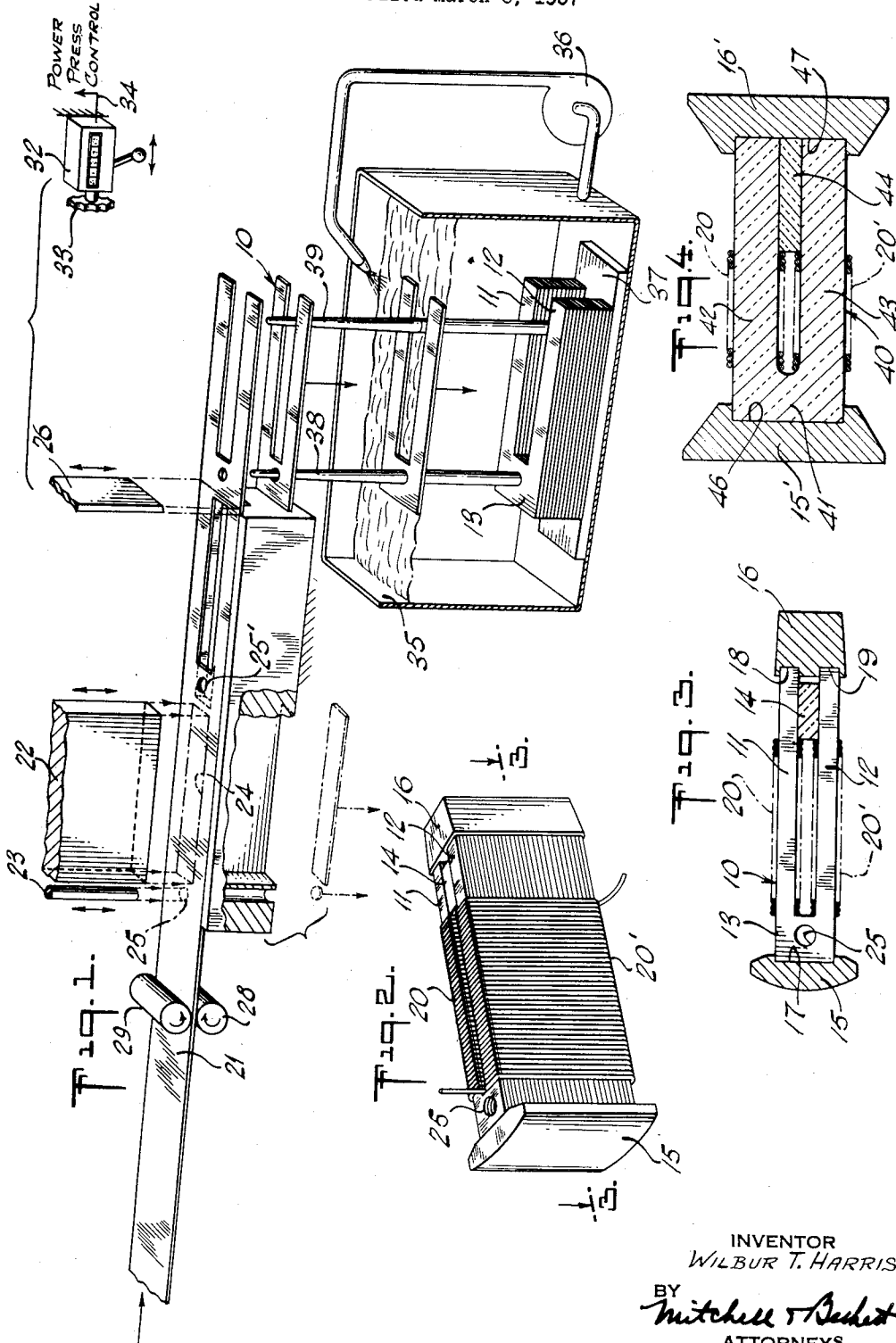


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TRANSDUCER ELEMENT
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TRANSDUCER ELEMENT

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My invention relates to an improved transducer construction and to a method of producing the same. This invention incorporates certain improvements over my copending application Serial No. 475,462, filed December 15, 1954, and is related to my application Serial No. 558,947, filed January 13, 1956. This application is a continuation-in-part of my copending application, Serial No. 559,657, filed January 17, 1956, now abandoned.

It is an object of the invention to provide an improved construction and method of the character indicated.

It is another object to provide a new transducer construction featuring important economies in the use of magnetostrictive materials without sacrificing efficiency of performance.

It is another object to provide an improved transducer construction in which important reductions in quantities of magnetostrictive metal scrap may be realized.

Other objects and various further features of novelty and invention will be pointed out or will occur to those skilled in the art from a reading of the following specification in conjunction with the accompanying drawings. In said drawings, which show, for illustrative purposes only, preferred forms of the invention:

Fig. 1 is a simplified view in perspective and partly broken away to reveal apparatus for carrying out part of my improved method of transducer construction;

Fig. 2 is a perspective view of a completed transducer element of my invention;

Fig. 3 is a sectional view in the plane 3—3 of Fig. 2; and

Fig. 4 is a sectional view similar to Fig. 3, but showing a modification.

Briefly stated, my invention contemplates an improved transducer construction in which magnetostrictive material is employed essentially only in that part of the magnetic circuit which is relied upon for magnetostrictive elongation and contraction. Thus, the basic core may be merely an elongated fork having spaced arms or legs bonded at one end by an integral yoke, and the magnetic circuit may be completed by a permanently magnetized ferrite block. Electrical coupling is developed to the legs, and counterweight end masses are separately fabricated and bonded to the longitudinal ends of the stack of laminations. The end counterweights are preferably precision-cast, with recesses conforming to the cross-section of the end of the magnetostrictive core received therein; for a laminated core, these recesses thus serve a jiggling function, and whether the core is cast or laminated, these recesses help to provide extended-surface contact for firmly bonding the counterweights to the core.

In my method of producing the laminated-core embodiment of my invention, a new lamination is sheared from a continuous strip of magnetostrictive metal, for each press cycle. The individual laminations are collected and automatically stacked in a parting-agent bath located directly beneath the newly cut-off piece. An automatic counting mechanism determines when the full stack has been accumulated and may serve to shut off the shearing

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operation until the stack has been removed and a new stacking jig placed beneath the cut-off location. The stack collected in the parting-agent bath is removed as a whole and placed in an annealing oven in an inert or reducing atmosphere and is thereafter chemically or otherwise treated in order that the laminations may have some measure of insulation inherent in their surfaces. The stack is then compressed and bonded in a consolidating operation.

Referring to Figs. 2 and 3 of the drawings, my invention is shown in application to an elongated transducer element comprising a stacked plurality of like laminations 10. Each lamination comprises laterally spaced elongated legs 11—12 integrally joined at a yoke end 13. A permanent-magnet ferrite block 14 spaces the free ends of the legs 11—12 and is bonded thereto; preferably, the block 14 is bonded at a location just short of the longitudinal ends of legs 11—12 so that these ends project beyond block 14. A head counterweight 15 and a tail counterweight 16 are each suitably recessed to receive the respective ends of the consolidated stack; the weights 15—16 are preferably of non-magnetic material, thereby avoiding shunting effects, A.C. flux penetration and eddy-current losses therein.

In the form shown, the head counterweight 15 receives the yoke end 13 of the stack at its recess 17; the head 15 is preferably of a material comprising essentially aluminum so as to be relatively light in weight. The head 15 is preferably precision-cast, and the recess 17 conforms closely to the cross section of the yoke end 13 so as to perform a self-jigging function when receiving the stacked laminations, thereby permitting establishment of a good bond to the stack. In like manner, the tail weight 16 is recessed at 18—19 to accommodate the projecting ends of the lamination legs 11—12, and the tail 16 is also preferably precision-cast so as closely to receive the legs 11—12 and to permit secure bonding; the tail weight 16 is relatively substantially heavier than the head weight 15 and is preferably of a zinc-alloy construction. Winding means 20 is linked to the magnetic circuit defined by legs 11—12—13 and by block 14, and in the form shown, separate windings of like numbered turns are linked to each of the legs 11—12. The windings 20—20' may be developed separately on forms having the cross section of the legs 11—12 and merely insertably applied to the legs 11—12 before the ferrite block 14 is bonded thereto.

In use, the element of Fig. 2 may form part of an array of similar elements, in side-by-side relation, with sets of legs 11—12 of adjacent elements either parallel to each other or slightly inclined (as when orienting the individual elements about a central support, from which the heads 15 project radially outwardly). In such an array, a sound-transparent boot or diaphragm would cover all heads. As far as each array element is concerned, end-for-end symmetrical loading is not necessary and is not intended; thus, the head weight 15 is preferably lighter than the tail weight 16, even when the radiation load is added to the head weight 15. With such proportioning, i.e., if the head 15, with its radiation load, is lighter than the tail 16, then higher displacement amplitude and greater radiation resistance may be realized.

In the mass production of laminations of the character indicated, I prefer to employ a two-stage process, which may involve a single power press operating on a continuous strip 21 of magnetostrictive metal. At a first stage, a rectangular punch 22 and a small central circular punch 23 develop openings 24—25 in the strip, thus defining the spaced stretches which ultimately become the legs 11—12 and also defining at 25 a hole in the yoke 13 for locating purposes. The power press may also carry a shear member 26 spaced by one lamination length from

the punch elements 22—23, so that when in a second location indexed by one lamination length (or by an integer multiple of lamination lengths) from the punch location, the locating hole 25 is poised to receive an element of indexing mechanism 28—29. In Fig. 1, I identify this location of the hole 25 by the designation 25'.

The indexing mechanism is shown schematically to comprise longitudinally reciprocating means including feed elements 38—29; the indexing means will be understood to incorporate means (not shown) for feeding one lamination length (or an integer multiple thereof) for each cycle of operation. Means (not shown) and either responsive to the indexing means 28—29 or to movement of some other recycling part of the press may engage the trip of counting mechanism 32 to determine when a desired number of laminations has been cut off. The counter is shown to include an adjustable knob 33 for preselecting the number of laminations to be cut in a given stack, and at 34 I suggest that, upon determination that the preselected number of laminations has been cut, a control function will be developed to temporarily shut off the production of further laminations.

In Fig. 1, the showing of tool elements and indexing mechanism is purely schematic, and it will suffice merely to describe the succession of events. As a first step, the punches 22—23 descend to punch out the holes 24—25. In the same reciprocation of the head of the power press, but with preferably slightly delayed action (due to use of a blade 26 which is shorter than other punch elements 22—23), the shear 26 descends to cut off a new lamination 10. The new lamination 10 drops off and the press head is withdrawn to permit indexing. The cycle then repeats.

In accordance with my invention, I provide for automatically stacking the newly formed laminations 10 in slightly spaced relation so as to facilitate subsequent heat treatment and surface-insulation treatment prior to consolidation. In the form shown, this is achieved in a bath 35 containing an aqueous suspension of parting agent, such as talc or milk of magnesia. Recirculating mechanism including a pump 36 assures continuous uniform suspension of the parting agent in the bath 35. A jig 37 may be seated on the bottom of bath 35 and may include an upstanding locating pin 38 poised to intercept the hole 25 of a newly cut off lamination as it begins to fall. I prefer that the upper end of the locating pin 38 shall be tapered so as to minimize the risk of fouling and so as to provide least possible friction to the free fall of each new lamination; this tapering preferably ends at or below the surface of the parting-agent fluid. Further accuracy of location may be achieved by employing a second pin 39 to locate between the free ends of the legs 11—12.

After the counting means 32 has determined that a stack of desired size has been accumulated on the jig 37, the production of further laminations is temporarily stopped so as to permit bodily removal of the jig 37 with its accumulated stack of laminations. The parting agent has assured adequate, though small, spacing between adjacent laminations so that the jig and stack may be placed as a unit in an annealing oven. Preferably, this is a conveyORIZED device and annealing takes place in a reducing atmosphere, such as a mixture of hydrogen and nitrogen. After annealing, the individual laminations are surface-treated to provide an oxidized film or surface for better electrical insulation between laminations. The chemical mechanism for performing this function is well known, and a black oxide may be readily developed on nickel laminations without requiring any further physical separation between laminations than that provided by the parting agent.

After surface-treating the annealed stack, the batch of laminations is clamped in a jig, with the yoke end 13 fitted into the cavity 17 of the head 15. Before fitting in this manner, the cavity 17 is first lined with a solvent-free type bonding agent (e.g. an epoxy resin), and the

yoke end is bonded to the head 15 in a first curing operation, which may be performed in a conveyORIZED low-temperature oven. The transducer element is thereafter finished by applying windings 20—21' of insulated wire, by insertion of the magnet 14, and by placement of the tail counterweight 16. In the latter step, bonding may be accomplished again in a conveyORIZED oven, using a suitable bonding agent as described in connection with bonding at the head end.

In Fig. 4, I show a modification in which the basic core 40 is of magnetostrictive ceramic, cast as a single piece into the generally forked shape shown, thereby defining a yoke portion 41 integrally joining two spaced elongated leg portions 42—43; the core ceramic is preferably of magnetically soft material (i.e. not permanent-magnet material), such as pure nickel ferrite (NiFe_2O_4). A permanent-magnet insert 44, which may also be of ferrite (as, for example, barium ferrite (BaFe_2O_4)), completes the flux path, and for efficiency, winding means 20—20' is developed along both legs 42—43. Head and tail weights of the proportions discussed at 15—16 in Fig. 3 may be bonded (as by an epoxy resin) to the longitudinal ends of the core 40, but I illustrate substantially matched head and tail weights 15'—16' to show the device for use as a bidirectional radiator, that is, for like (but opposed) radiation at both longitudinal ends. Extensive-surface bonding is achieved by fitting the wound-core ends in suitable recesses 46—47 in the head and tail weights 15'—16'.

Fig. 4 may also be viewed as illustrative of an embodiment of the invention in which the core 40 is itself permanently magnetized, and the insert 44 is merely an unpolarized coupler, in order to complete the magnetic flux path. In such event, the material of the permanently magnetized core 40 is preferably a nickel ferrite having a relatively small addition of cobalt ferrite, while the coupler is preferably a manganese-zinc ferrite.

It will be seen that I have described at basically simple transducer-element construction and method of construction, featuring economy of the use of magnetostrictive material and reducing to a minimum the number of separate handling operations required in the production of the assembly. I find that even though the head and tail weights 15—16 (or 15'—16') are separately formed and are therefore not integral with the core 10 (or 40), the bonding at precision-formed cavities 17—18—19 (or 46—47) may be good, hard and permanent so that efficiency need not be sacrificed.

While I have described the invention in detail for the preferred forms illustrated, it will be understood that modifications may be made within the scope of the invention as defined in the claims which follow.

I claim:

1. In an electromechanical transducer, a substantially continuous and closed magnetic flux-path core comprising two laterally spaced elongated legs of magnetostrictive material joined by an integral yoke at one end, said legs having a width measured in said lateral direction of spacing between said legs and a height measured in a direction at right angles to said width, said legs defining substantially continuous flux-transmitting paths therethrough over a plurality of planes extending widthwise of said legs from opposing edges of said legs outwardly for appreciable distances, a magnetic connecting element formed of magnetic flux conducting material connected between said legs at points along the length remote from said yoke and extending along the height of said legs for a substantial distance in close flux-conducting adjacency with a plurality of said flux-transmitting planar paths at said opposed edges of said legs, means for magnetically polarizing said core, winding means linked to said legs, and end counterweights bonded to the respective longitudinal ends of said legs and yoke.
2. The transducer of claim 1, in which said legs and

yoke are formed from a single block of magnetostrictive material.

3. The transducer of claim 2, in which said magnetic connecting element is permanently magnetized and comprises said magnetic polarizing means.

4. The transducer of claim 2, in which a portion of said leg-yoke combination is permanently magnetized and comprises said magnetic polarizing means.

5. The transducer of claim 2, in which said end counterweights are recessed, said respective longitudinal ends of said legs and yoke, and at least a portion of said magnetic connecting element, being received within said recesses.

6. The transducer of claim 2, in which the end counterweight bonded to said yoke is relatively light compared to the end counterweight bonded to the other longitudinal end of said legs.

7. The transducer of claim 1, in which said legs and yoke are formed from a plurality of laminations planarly oriented in the direction of and comprising said flux-transmitting planar paths.

8. The transducer of claim 7, in which said magnetic connecting element is permanently magnetized and comprises said magnetic polarizing means.

9. The transducer of claim 7, in which a portion of said leg-yoke combination is permanently magnetized and comprises said magnetic polarizing means.

10. The transducer of claim 7, in which said end counterweights are recessed, said respective longitudinal ends of said legs and yoke, and at least a portion of said magnetic connecting element, being received within said recesses.

11. The transducer of claim 7, in which the end counterweight bonded to said yoke is relatively light compared to the end counterweight bonded to the other longitudinal end of said legs.

12. The transducer of claim 1, in which said magnetic connecting element is permanently magnetized and comprises said magnetic polarizing means.

13. The transducer of claim 1, in which a portion of said leg-yoke combination is permanently magnetized and comprises said magnetic polarizing means.

14. The transducer of claim 1, in which said end counterweights are recessed, said respective longitudinal ends of said legs and yoke, and at least a portion of said magnetic connecting element, being received within said recesses.

15. The transducer of claim 1, in which the end counterweight bonded to said yoke is relatively light compared to the end counterweight bonded to the other longitudinal end of said legs.

16. In an electromechanical transducer, a continuous and closed magnetic flux-path core, comprising a consolidated stacked plurality of like flat laminations of magnetostrictive metal, said laminations being of forked configuration, including two laterally spaced elongated legs of uniform width joined by an integral yoke at one end, a permanently magnetized ferrite block bonded to and joining said legs at the other longitudinal end thereof, said ferrite block being of height sufficient to overlap the height of said legs, whereby magnetic flux may thread directly and uniformly between said block and the edges of all laminations of said plurality, winding means linked to the legs of the magnetic circuit defined by said stacked laminations and by said block, and recessed end counterweights fitting the respective longitudinal ends of said legs and yoke and bonded thereto.

17. In an electromechanical transducer, a continuous

and closed magnetic flux-path core, comprising a consolidated stacked plurality of like flat laminations of magnetostrictive metal, said laminations including two laterally spaced elongated legs of uniform width joined by an integral yoke at one end, a permanently magnetized ferrite block bonded to and joining said legs at the other longitudinal end thereof, said ferrite block being of height overlapping the combined height of said legs, whereby magnetic flux may thread directly and uniformly between said block and the edges of all laminations of said plurality, separate like windings coupled to the respective longitudinally extending legs of said stack, and recessed end counterweights fitting the respective longitudinal ends of said legs and yoke and bonded thereto.

18. In an electromechanical transducer, a continuous and closed magnetic flux-path core, comprising a consolidated stacked plurality of like flat laminations of magnetostrictive metal, said laminations including two laterally spaced elongated legs of uniform width joined by an integral yoke at one end, a permanently magnetized ferrite block bonded to and joining said legs at the other longitudinal end thereof, said block overlapping corresponding parts of the edges of all said laminations, whereby magnetic flux may thread directly and uniformly between said block and the edges of all laminations of said plurality, winding means linked to the magnetic circuit defined by said stacked laminations and by said block, a recessed head weight of relatively light metal fitting the yoke end of said core and bonded thereto, and a recessed tail weight of relatively heavy metal fitting the other longitudinal end of said core and bonded thereto.

19. A transducer according to claim 18, in which the material of said head comprises essentially aluminum.

20. A transducer according to claim 18, in which the material of said tail comprises essentially a zinc alloy.

21. In an electromechanical transducer, a continuous and closed magnetic flux-path core, comprising a consolidated stacked plurality of like flat laminations of magnetostrictive metal, said laminations including two laterally spaced elongated legs of uniform width joined by an integral yoke at one end, a permanently magnetized ferrite block bonded to and joining said legs at the other longitudinal end thereof, said block being in close and direct flux-conducting adjacency with corresponding edge parts of both legs of all laminations, said block being bonded at a location longitudinally short of the other ends of said laminations, whereby the ends of said legs project beyond said block, winding means linked to the magnetic circuit defined by said stacked laminations and by said block, and head and tail weights bonded to the respective longitudinal ends of said stack, said tail weight having two separate recesses conforming to the individual cross sections of the projecting ends of said legs and receiving said projecting ends and bonded thereto.

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