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(54) **Title**: METHOD AND APPARATUS FOR MANUFACTURING BATTERY CELLS BY SPIN CASTING

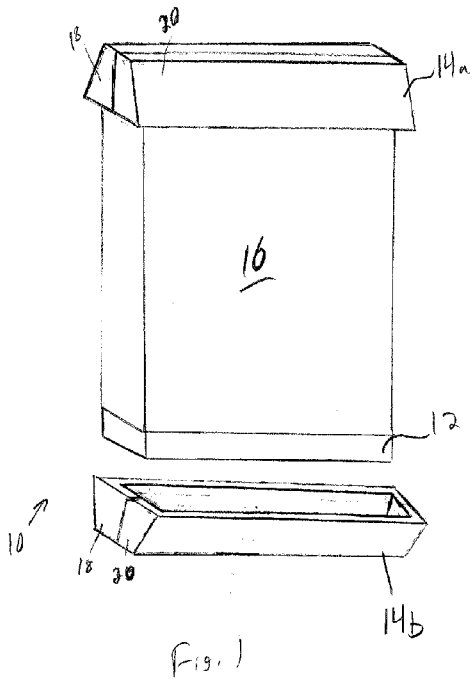

Fig. 1

(57) **Abstract**: A method of manufacturing a battery cell is provided. The method includes securing at least one end piece onto at least one end of a main portion of the battery cell, spinning the battery cell such that the at least one end piece revolves around an axis of the main portion and heating the at least one end piece during the spinning. A spin molding apparatus and a battery cell are also provided.

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METHOD AND APPARATUS FOR MANUFACTURING BATTERY CELLS BY SPIN CASTING

[0001] The present invention relates generally to a method and apparatus for manufacturing battery cells and more specifically to a method and apparatus for manufacturing battery cells by spin casting and spin casted battery cells.

SUMMARY OF THE INVENTION

[0002] A method of manufacturing a battery cell is provided that includes securing at least one end piece onto at least one end of a main portion of the battery cell, spinning the battery cell such that the at least one end piece revolves around an axis of the main portion and heating the at least one end piece during the spinning.

[0003] A method of manufacturing a battery cell is also provided that includes providing at least one end piece material onto at least one end of a main portion of the battery cell, spinning the battery cell such that the at least one end piece material revolves around an axis of the main portion and heating the at least one end piece material during the spinning to cure the end piece material into an end piece.

[0004] A spin molding apparatus is also provided. The spin molding apparatus includes a battery cell holding portion for securing a battery cell. The battery cell holding portion includes at least one heater for heating at least one end piece of the battery cell. The spin molding apparatus also includes a drive for rotating the cell holding portion about an axis of the cell holding portion. The drive rotates the cell holding portion about the axis of the cell holding portion such that at least one end piece of the battery cell revolves around an axis of a main portion of the battery cell.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The present invention is described below by reference to the following drawings, in which:

[0006] Fig. 1 shows a battery cell having molds mounted at ends thereof according to an embodiment of the present invention;

[0007] Fig. 2 shows spin molding apparatus according to an embodiment of the present invention;

[0008] Fig. 3 shows a heater block of the spin molding apparatus according to an embodiment of the present invention;

[0009] Fig. 4 shows vertical struts of the spin molding apparatus according to an embodiment of the present invention;

[0010] Fig. 5 shows a shaft of the spin molding apparatus according to an embodiment of the present invention;

[0011] Fig. 6 shows the connection between a heater block, a strut and links of the spin molding apparatus according to an embodiment of the present invention;

[0012] Fig. 7 shows a detachable insulator of the spin molding apparatus according to an embodiment of the present invention;

[0013] Fig. 8 shows a detachable cooler of the spin molding apparatus according to an embodiment of the present invention;

[0014] Fig. 9 shows a bracket of the spin molding apparatus according to an embodiment of the present invention;

[0015] Fig. 10 shows a cut-away view of the arrangement of a Mercotac connector, a torque arm and the shaft of the spin molding apparatus according to an embodiment of the present invention;

[0016] Fig. 11 shows a cut-away view of the arrangement of pillow blocks, a timing belt pulley, the torque arm and the Mercotac connector with respect to one axial of the shaft according to an embodiment of the present invention;

[0017] Fig. 12 shows one of the molds according to an embodiment of the present invention;

[0018] Fig. 13 shows one of the pillow block of the spin molding apparatus according to an embodiment of the present invention;

[0019] Fig. 14a shows one of the links of the spin molding apparatus according to an embodiment of the present invention;

[0020] Fig. 14b shows a side locking bar of the spin molding apparatus according to an embodiment of the present invention;

[0021] Fig. 15 shows a guard for the spin molding apparatus according to an embodiment of the present invention; and

[0022] Fig. 16 shows controls for the spin molding apparatus according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0023] Embodiments of the present invention use a spin casting method to make battery cells. The spin casting method may allow for broad scale and inexpensive production of battery cells and is compatible with rapid prototyping and mass customization objectives for the military. The spin casting method also has dual use potential, including for making rapid recharge batteries. The spin casting method may allow battery cells to be produced in approximately 5 minutes, while conventional methods take approximately 8 hours.

[0024] Fig. 1 shows a battery cell 10 in an intermediate form with a first mold 14a mounted on a first end of cell 10 and a second mold 14b, which is pulled back away from cell 10, for mounting on a second end of cell 10. In one preferred embodiment, battery cell 10 is a lithium ion battery cell. Molds 14a, 14b each retain an end piece 12 on the respective end of a main portion 16 of cell 10. Battery cell 10 is in an intermediate form because end pieces 12 are not yet permanently secured to main portion 16. In one preferred embodiment each end piece 12, before being permanently secured to main portion, is an end piece material in the form of a strip of molding compound having a consistency of putty that is loaded onto main portion 16. The molding compound may be formed of a polymer, which in one preferred embodiment is a thermoset polymer, most

preferably thermoset polyester. Thermoset polyester may be selected based on its solvent resistance, adhesion to metals, low curing temperatures and cost. After one end piece 12 for example is loaded onto the first end of cell 10, mold 14a is placed over the end piece 12, and after another end piece 12 is loaded onto the second end of cell 10, mold 14b is placed over the end piece 12. In another preferred embodiment, end pieces 12 may be loaded into molds 14a, 14b before being loaded onto ends of main portion 16 and are held on the ends of main portion 16 by molds 14a, 14b. Each mold 14a, 14b may include two halves 18, 20. After molds 14a, 14b are secured on the ends of main portion 16, cell 10 is placed into a spin molding apparatus 30, as shown in Fig. 2, to heat end pieces 12, cure the molding compound and permanently secure end pieces 12 onto main portion 16.

[0025] Fig. 2 shows spin molding apparatus 30 according to one embodiment of the present invention. Spin molding apparatus 30 includes a battery cell holding portion 32 having two heater blocks 34a, 34b for contacting and heating respective molds 14a, 14b. Each heater block 34a, 34b includes a respective mold receiving portion 36 defined therein for receiving the respective mold 14a, 14b such that each heater block 34a, 34b surrounds one end piece 12. In one preferred embodiment, heater blocks 34a, 34b are formed as shown in Fig. 3. Heater blocks 34a, 34b are held together at the longitudinal ends thereof by vertical struts 38a, 38b, which are each coupled to respective axial sides 40a, 40b of a hollow shaft 40. In one preferred embodiment, struts 38a, 38b are formed as shown in Fig. 4. Heating blocks 34a, 34b may be electrically coupled to a power source by heating wiring 35 passing from heating blocks 34a, 34b into the inside of hollow shaft 40 via holes 37 in shaft 40, which is shown in Fig. 5 according to one preferred embodiment of the present invention.

[0026] In order to allow cell 10, with molds 14a, 14b mounted thereon, to be inserted into holding portion 32, either one of heater blocks 34a, 34b may be swung away from one of vertical struts 38a, 38b. A first hinge, which in the embodiment shown in Fig. 2 includes two hinge links 42a, may be provided to connect strut 38a and heater blocks 34a and to allow heater block 34a to be swung away from strut 38b. One preferred embodiment of the connection between heater block 34a, strut 38a and links 42a is shown in Fig. 6. A second hinge, which in the embodiment shown in Fig. 2 includes hinge links 42b, may be

provided to connect strut 38b and heater block 34b and to allow heater block 34ab to be swung away from vertical strut 38a. Heater blocks 34a, 34b may include bore holes therein at the longitudinal ends thereof into which cap screws may be inserted to fix heater blocks 34a, 34b to vertical struts 38a, 38b. Four cross rods 46, two on each side of cell 10 when cell 10 is in holding portion 32, extending between vertical struts 38a, 38b contact faces of cell 10 to help secure cell in holding portion 32. Four side locking bars 47, two on each lateral side of cell 10 when cell 10 is in holding portion 32, may be provided in cell holding portion 32 for preventing lateral movement of cell 10 during the spin molding. As shown in Figs. 6 and 14b, side locking bars 47 may each include two bores holes 47a therein, each for receiving one of cross rods 46 such that side locking bars 47 each attached to two cross rods 46.

[0027] Shaft 40 is rotatably held in place on a base plate 50 by bearing pillow blocks 52, (one of pillow blocks 52 is shown in greater detail in Fig. 13), four of which are provided in the embodiment shown in Fig. 2. At least the outer pillow blocks 52 may each include a torque arm 53 attached thereto extending to the respective end of shaft 40. A timing belt drive 56 is provided on base plate 50 for rotating shaft 40 to spin battery cell holding portion 32 and the cell 10 retained therein about a central axis of shaft 40, as shown by arrow 58. Timing belt drive 56 includes a timing belt pulley 56a fixedly mounted on shaft 40, a timing belt 56b coupled to the circumference of pulley 56a for rotating pulley 56a and a DC motor 56c for driving timing belt 56b. Motor 56c is mounted on base plate 50 by a bracket 56b, which is shown in more detail in Fig. 9. In a preferred embodiment base plate 50 is formed as part of a heavy marble table to secure spin molding apparatus 30 and to resist the effects of vibration and imbalance that may be caused by the operation of spin molding apparatus 30.

[0028] A detachable insulator 60, one preferred embodiment of which is shown in Fig. 7, may be placed over each heater block 34a, 34b and held in place by quick release pins. In one preferred embodiment, insulator 60 may be formed of G-10 garolite and may include end plates 62, which may be stainless steel, having holes which quick release pins may pass through to removably fix insulator 60 on the respective heater block 34a, 34b.

A cross-drilling in the holes permits a ball-detent at an end of each quick release pin to pop up and retain the pin (and insulator 60) in place.

[0029] After detachable insulators 60 are in place on heater blocks 34a, 36b and cell 10 is secured in cell holding portion 32, motor 56c is run up to speed for spinning battery cell 10 such that end pieces 12 revolve around an axis of main portion 16. Drive 56 rotates cell holding portion 32 about an axis of cell holding portion 32 such that end pieces 12 revolve around the axis of main portion 16. The actual RPM of the spin molding apparatus 30 may be checked by a tachometer (~ 500 RPM, which will generate around 10 g centripetal acceleration on the molding compound in end pieces 12) with a reflective target stuck to a strut, preferably on axial sides 40a, 40b of a shaft 40, and a sensor mounted on a leg of one of pillow blocks 52. Heater blocks 34a, 34b, which heat up quickly, are then turned on such that heater blocks 34a, 36b heat end pieces 12 during the spinning. In one preferred embodiment, each heater block 34a, 34b holds two 10 inch cartridge heaters, each rated at 725 watts. An appropriate temperature for rapid curing (~ 3 minutes) of the molding compound may be around 280 degrees Fahrenheit. Heater blocks 34a, 34b may be connected in series (inside of hollow shaft 40) and run on 220 VAC. Fig. 10 shows a cut-away view of the arrangement of a Mercotac connector 64, torque arm 53 and shaft 40 and Fig. 11 shows a cut-away portion of axial side 40a of shaft 40, showing the arrangement of pillow blocks 52, timing belt pulley 56a, torque arm 53 and a Mercotac connector 64 with respect to shaft 40. Mercotac connectors 64 may be provided inside of hollow shaft 40 at sides 40a, 40b of shaft 40 and may have rotating contacts for both power and for a thermocouple temperature sensor.

[0030] After about 2 to 4 minutes the molding compound of end pieces 12 sets and end pieces 12 are bonded to main portion 16. The spinning of cell holding portion 32 may then be stopped, heaters 34a, 34b are turned off and insulators 60 may be replaced with a detachable cooler, which in one preferred embodiment are finned aluminum heat sinks 66 as shown in Fig. 8. After finned aluminum heat sinks 66, which may be removably fixed to respective heater blocks 34a, 34b in the same manner insulators 60 are removably fixed to respective heater blocks 34a, 34b, are placed over heater blocks 34a, 34b, cell holding portion 32 may be spun again by drive 56 to cool down heater blocks 34a, 34b

fairly quickly. Once fairly cool, spin molding apparatus 30 may be stopped to remove cell 10. Hinge links 42a, 42b, which as shown in greater detail in Fig. 14a, retain the hinged end of the respective heater block 34a, 34b, while allowing one or both of heating blocks 34a, 34b to be swung out of the way for removable of cell 10. In one preferred embodiment only one block 34a, 34b is moved to extract cell 10. Molds 14a, 14b may remain attached to cell 10 as cell 10 is removed from cell holding portion 32 and may then be pried off from cell 10 to exposed end pieces 12, which are securely attached to main portion 16 b the spinning of cell 10 in spin molding apparatus 10. As shown in Fig. 12, molds 14a, 14b may each have a line of vent holes 70 (~ 1/16 inch diameter for example) running down the center split, which align with larger holes 72 (~ 1/8 inch diameter for example) in heater blocks 34a, 34b, as shown in Fig. 3, and holes 74 (~ 1/8 inch diameter for example) in insulators 60, as shown in Fig. 6. Holes 70, 72, 74 vent air and let the molding compound of end pieces 12 flow towards main portion 16. Any flashing of end pieces 12 may be trimmed off after molds 14a, 14b are removed.

[0031] In one alternative embodiment, the material used to form end pieces 12 may be provided in liquid form into molds 14a, 14b by an apparatus that is integral with, removable attachable to or separate from spin molding apparatus 30.

[0032] Since spin molding apparatus 30 poses a lethal hazard if parts fall off during spinning, a substantial guard 80, which is shown in Fig. 15, may be provided over spin molding apparatus 30 which may be easily swung out of the way for access to spin molding apparatus 30. In order to easily swing guard 80 for access, guard 80 may be supported by gas springs or struts. In one preferred embodiment, guard may be made of mild steel, which is for example 1/8 inch thick and painted or powder-coated finish. Lexan windows 82 may be provide on the sides guard 80 spin molding apparatus 30 operate when guard 80 is closed.

[0033] Fig. 16 shows one preferred embodiment of controls 90 for spin molding apparatus 30.

[0034] In the preceding specification, the invention has been described with reference to specific exemplary embodiments and examples thereof. It will, however, be evident that

various modifications and changes may be made thereto without departing from the broader spirit and scope of invention as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative manner rather than a restrictive sense.

WHAT IS CLAIMED IS:

1. A method of manufacturing a battery cell comprising:

securing at least one end piece onto at least one end of a main portion of the battery cell;

spinning the battery cell such that the at least one end piece revolves around an axis of the main portion; and

heating the at least one end piece during the spinning.

2. The method as recited in claim 1 further comprising cooling the at least one end piece after the heating.

3. The method as recited in claim 1 wherein the cooling is performed as the battery cell is spun such that the at least one end piece revolves around an axis of the main portion.

4. The method as recited in claim 1 wherein the at least one end piece is formed of a molding compound having a consistency of putty.

5. The method as recited in claim 4 wherein the molding compound is a thermoset polymer.

6. The method as recited in claim 5 wherein the thermoset polymer is thermoset polyester.

7. The method as recited in claim 1 wherein the at least one end piece is secured onto at least one end of the main portion of the battery cell by at least one mold.

8. The method as recited in claim 7 wherein the at least one end piece includes two end pieces and the at least one mold includes two molds, each of the end pieces being secured onto one end of the main portion by one of the molds.

9. The method as recited in claim 1 wherein the heating cures the at least one end piece to bond the at least one end piece to the main portion.

10. A battery cell formed by the method as recited in claim 1.

11. A method of manufacturing a battery cell comprising:

providing at least one end piece material onto at least one end of a main portion of the battery cell;

spinning the battery cell such that the at least one end piece material revolves around an axis of the main portion; and

heating the at least one end piece material during the spinning to cure the end piece material into at least one end piece.

12. The method as recited in claim 11 further comprising cooling the at least one end piece after the heating.

13. The method as recited in claim 11 wherein the cooling is performed as the battery cell is spun such that the at least one end piece material revolves around an axis of the main portion.

14. The method as recited in claim 11 wherein the at least one end piece material is a molding compound having a consistency of putty.

15. The method as recited in claim 14 wherein the molding compound is thermoset polyester.

16. The method as recited in claim 11 wherein the at least one end piece material is provided onto at least one end of the main portion of the battery cell by at least one mold.

17. The method as recited in claim 11 wherein the heating bonds the at least one end piece to the main portion.

18. A battery cell formed by the method as recited in claim 11.

19. A spin molding apparatus comprising:

a battery cell holding portion for securing a battery cell, the battery cell holding portion including at least one heater for heating at least one end piece of the battery cell;

a drive for rotating the cell holding portion about an axis of the cell holding portion, the drive rotating the cell holding portion about the axis of the cell holding portion such that at least one end piece of the battery cell revolves around an axis of a main portion of the battery cell.

20. The spin molding apparatus recited in claim 19 wherein the at least one heater includes at least one heater block configured to surround the at least one end piece.

21. The spin molding apparatus recited in claim 20 wherein the at least one heater block includes two heater blocks and the at least one end piece includes two end pieces, each heater block configured to surround one of the end pieces.

22. The spin molding apparatus recited in claim 19 further comprising at least one detachable insulator configured for placing over the at least one heater.

23. The spin molding apparatus recited in claim 19 further comprising at least one detachable cooler configured for placing over the at least one heater.

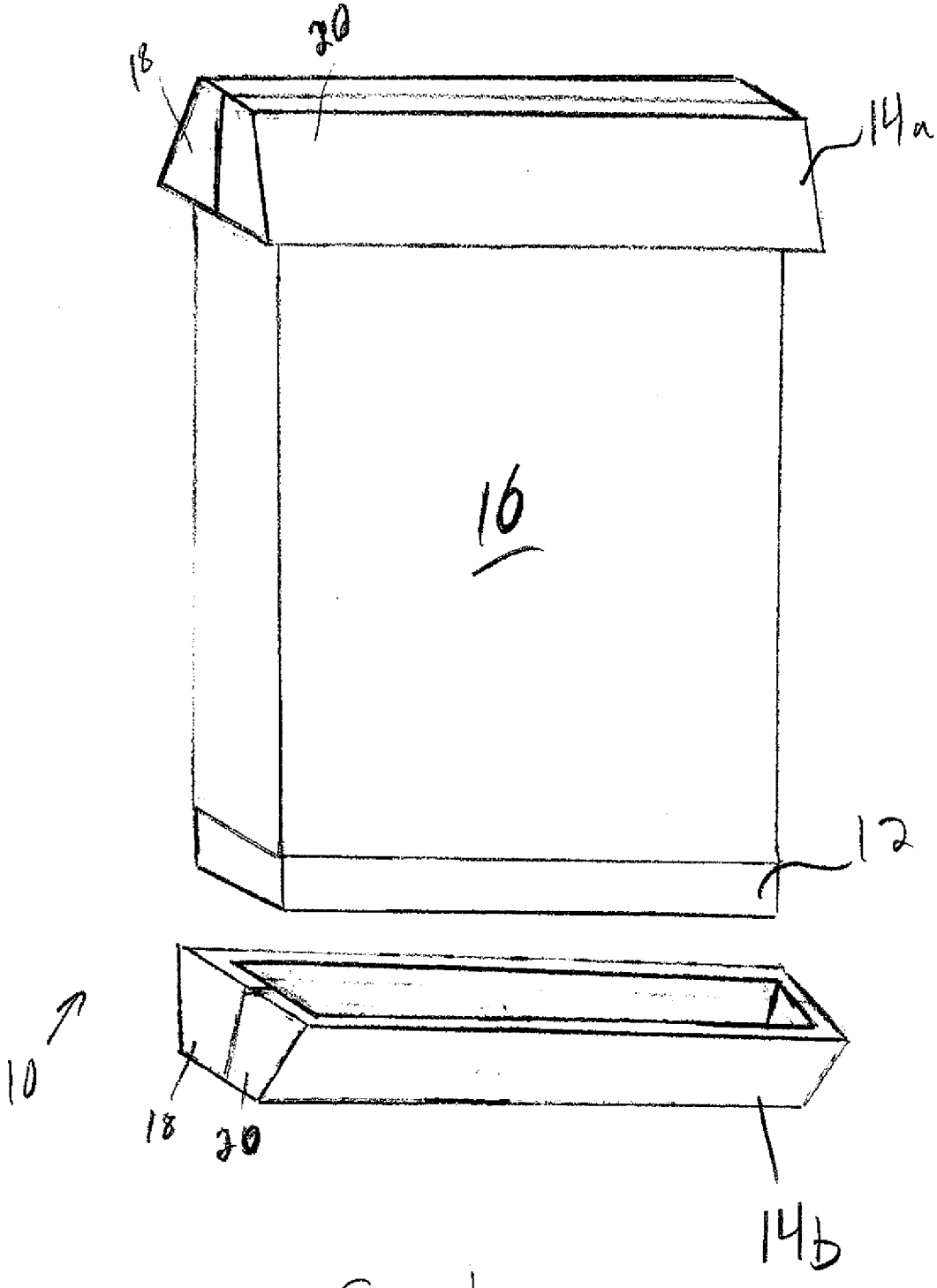


Fig. 1

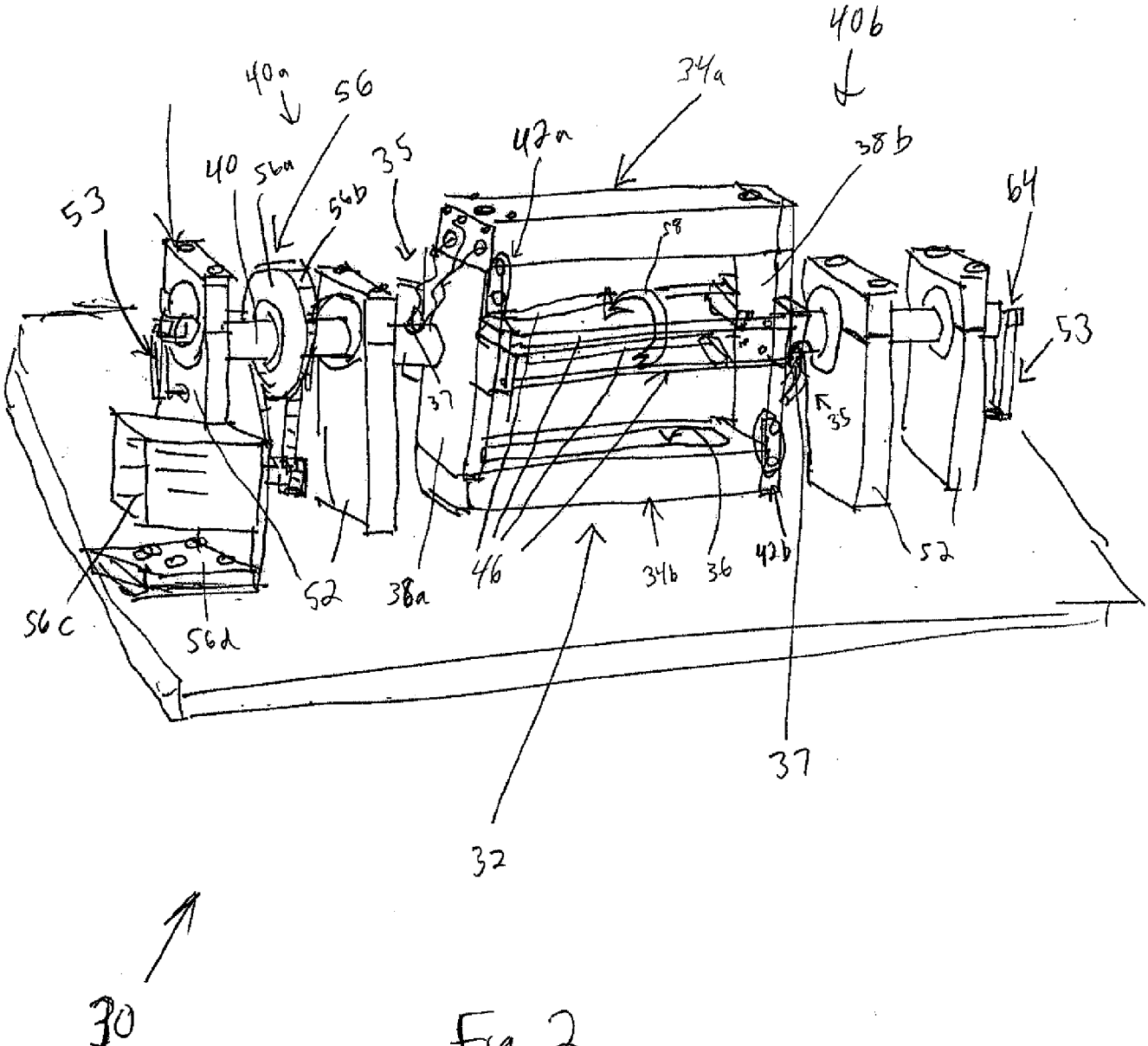

40b
34a
40a
56
42a
38b
64
40
56a
56b
35
53
58
53
37
35
52
56c
56d
52
38a
46
34b
36
42b
37
32
30

Fig. 2

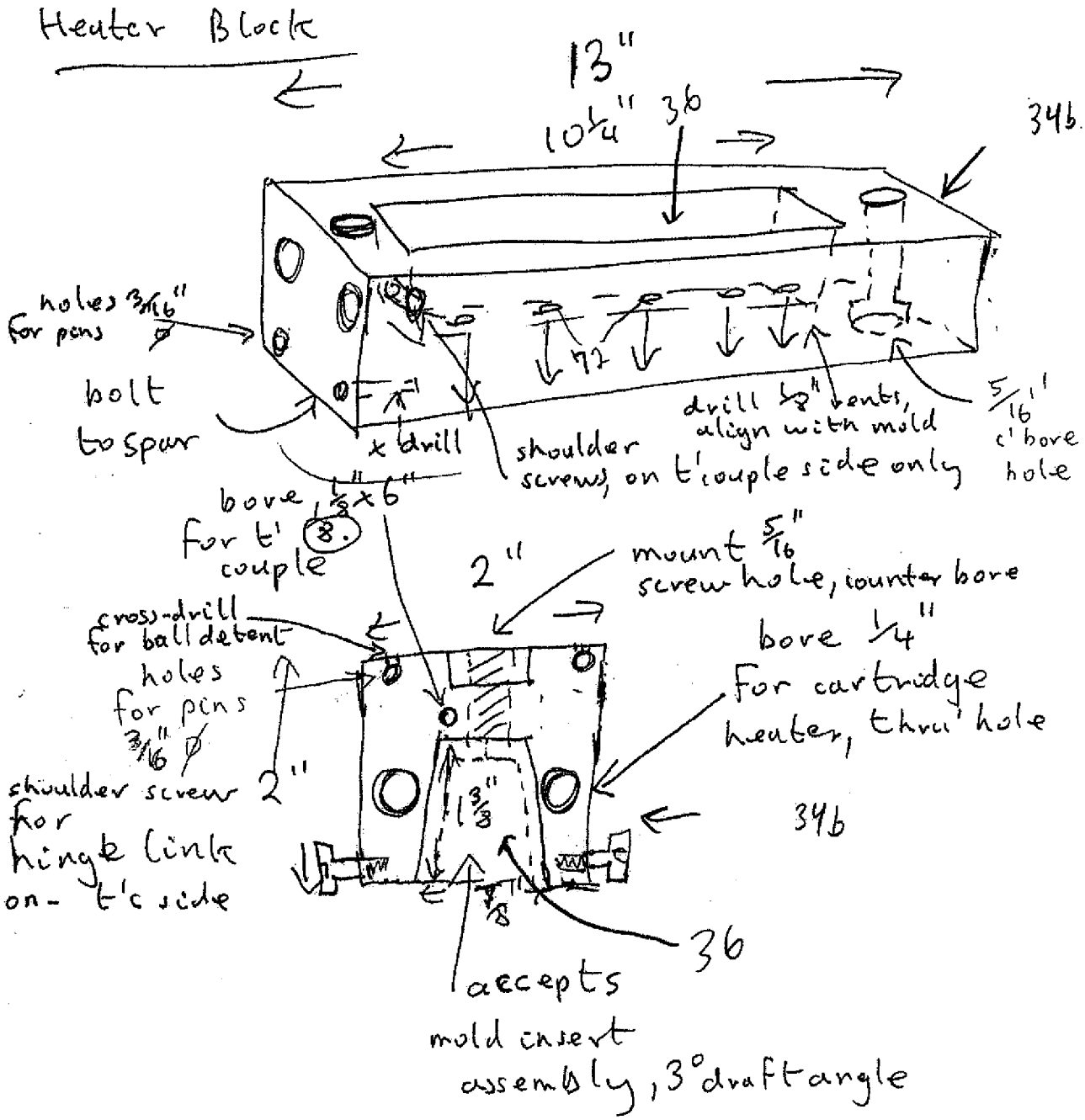
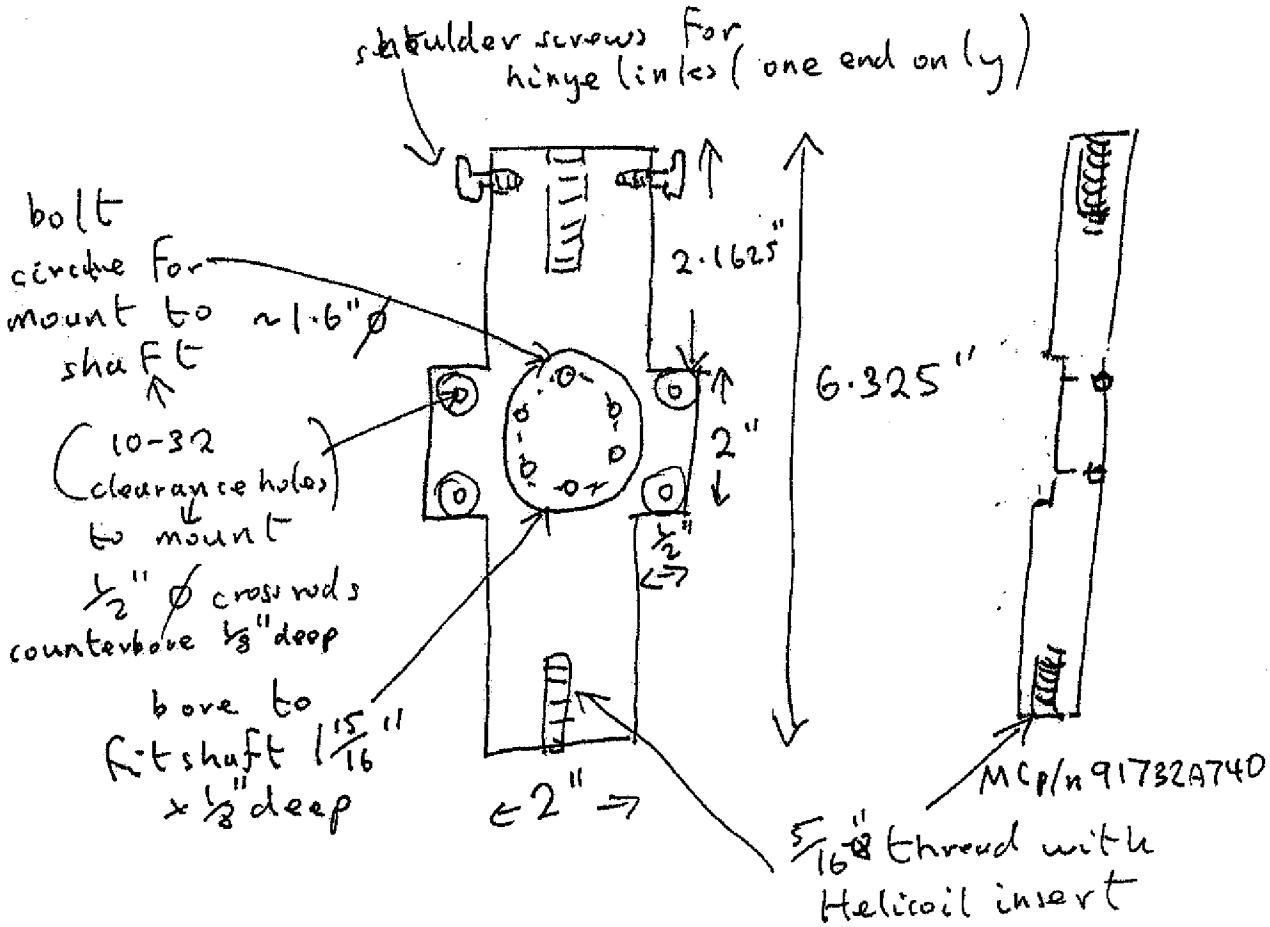

Heater Block
13"
10¼"
36
34b
holes 3/16" for pins
bolt to spur
x drill
shoulder screws, on t'couple side only
drill ½" bottom, align with mold
5/16" c'bore hole
bore 1/8 x 6" for t' couple
8.
2"
mount 5/16 screw hole, counter bore
bore ¼" For cartridge heater, thru' hole
cross-drill for ball detent
holes for pins 3/16" ø
shoulder screw for hinge link on- t'c side
2"
1 3/3"
34b
36
accepts mold insert assembly, 3° draft angle
material, aluminum, 2" x 2"

Fig. 3

Strut

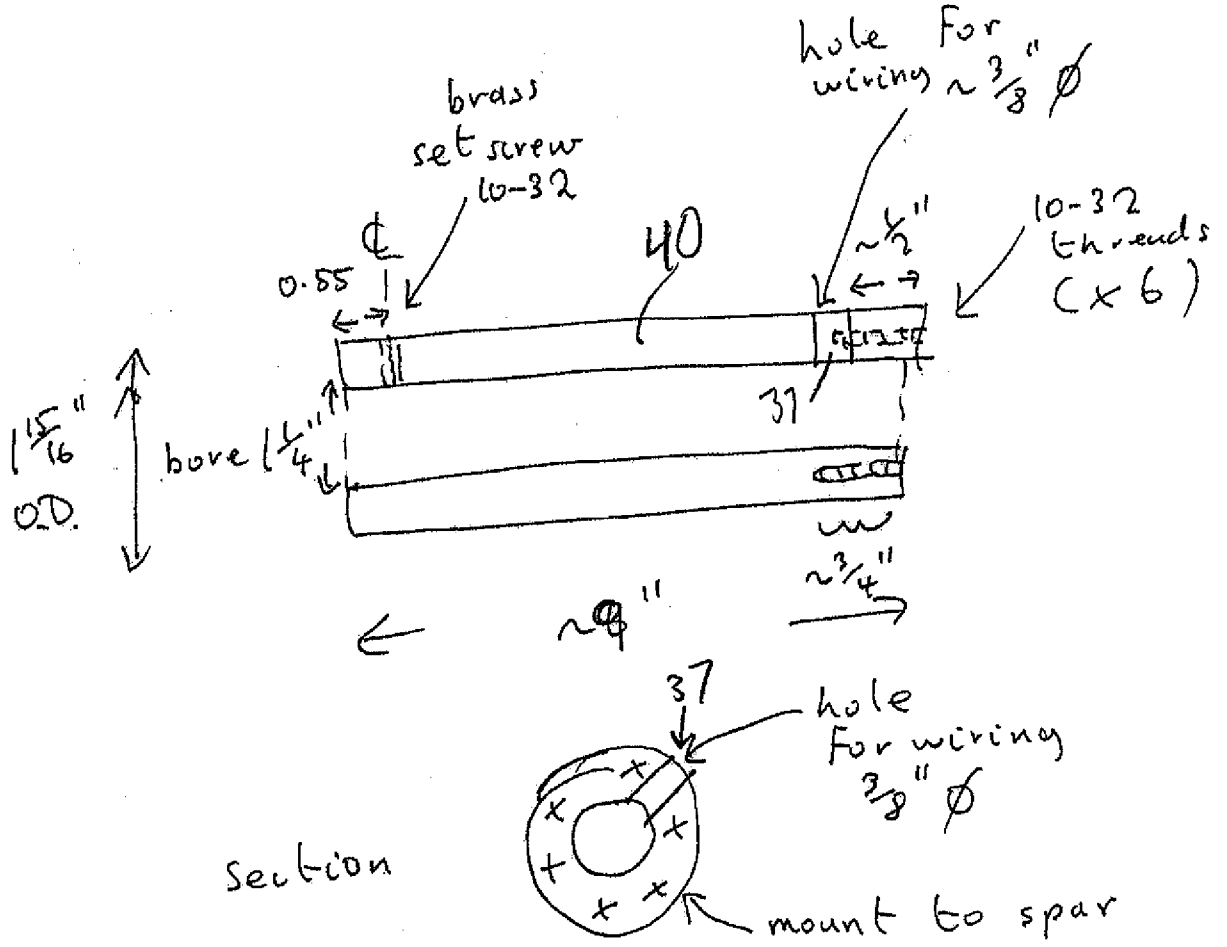


matl. G10/ FR4, ¾" thick
3" bar, McMCarr p/n 8557K55

×2

Fig. 4

Shaft



material, steel

Finish, black oxide / or S.S.

x2

Fig. 5

Strut Assembly

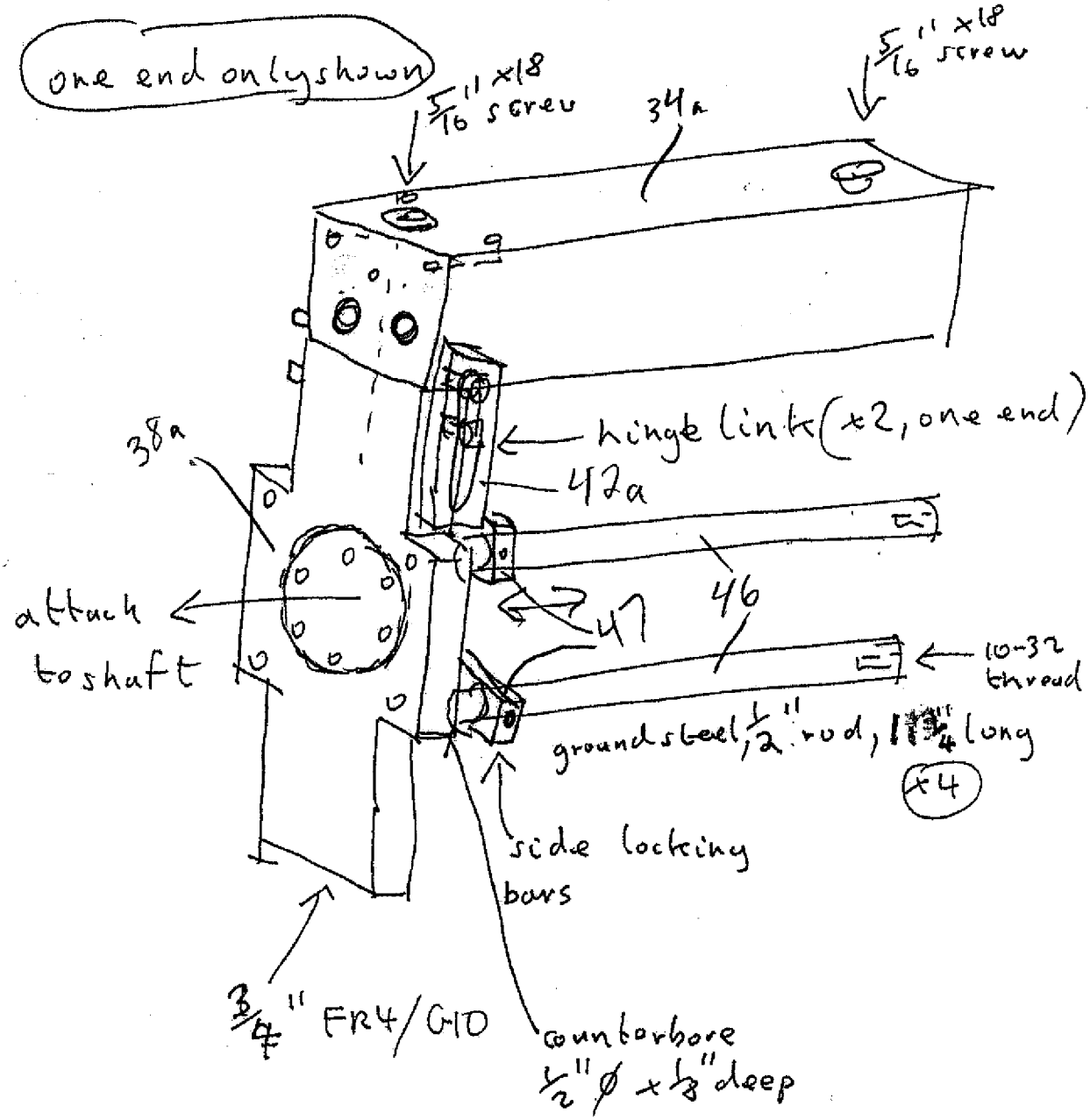
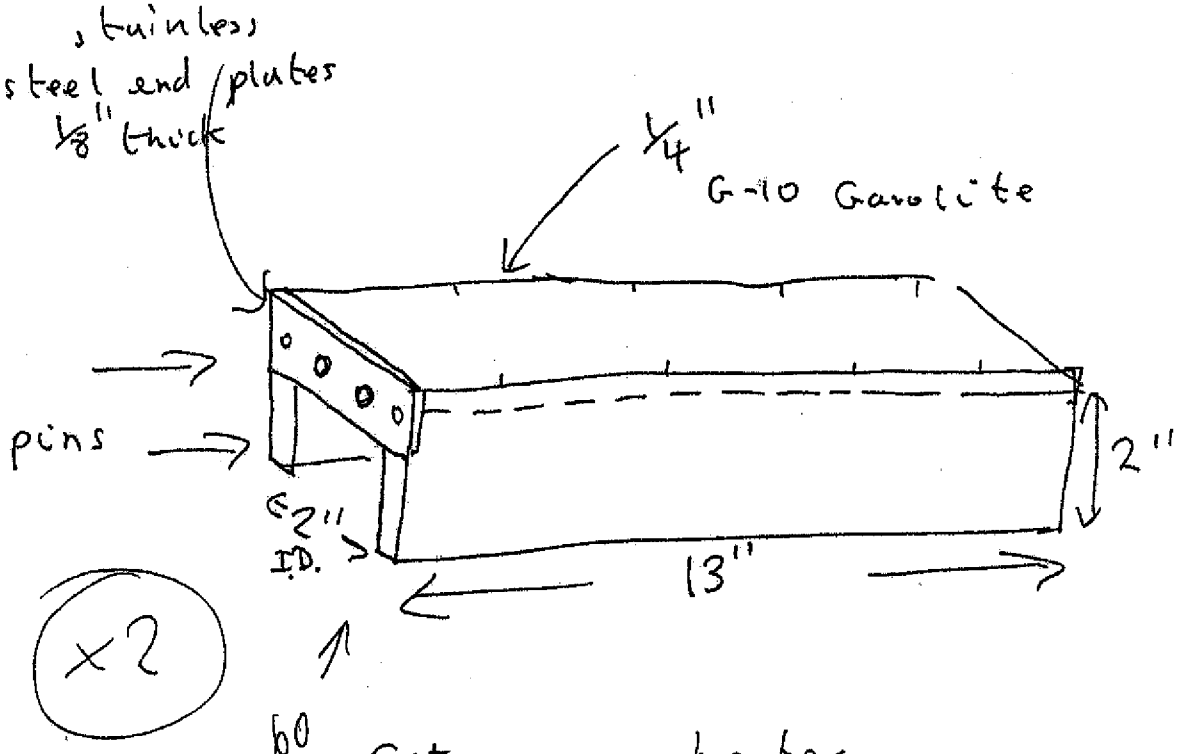


Fig. 6

Detachable Insulator



fits over heater
- secured with pins

e.g. McMCarr p/n 92385A013
push button, quick-release

Fig. 7

Detachable Cooler

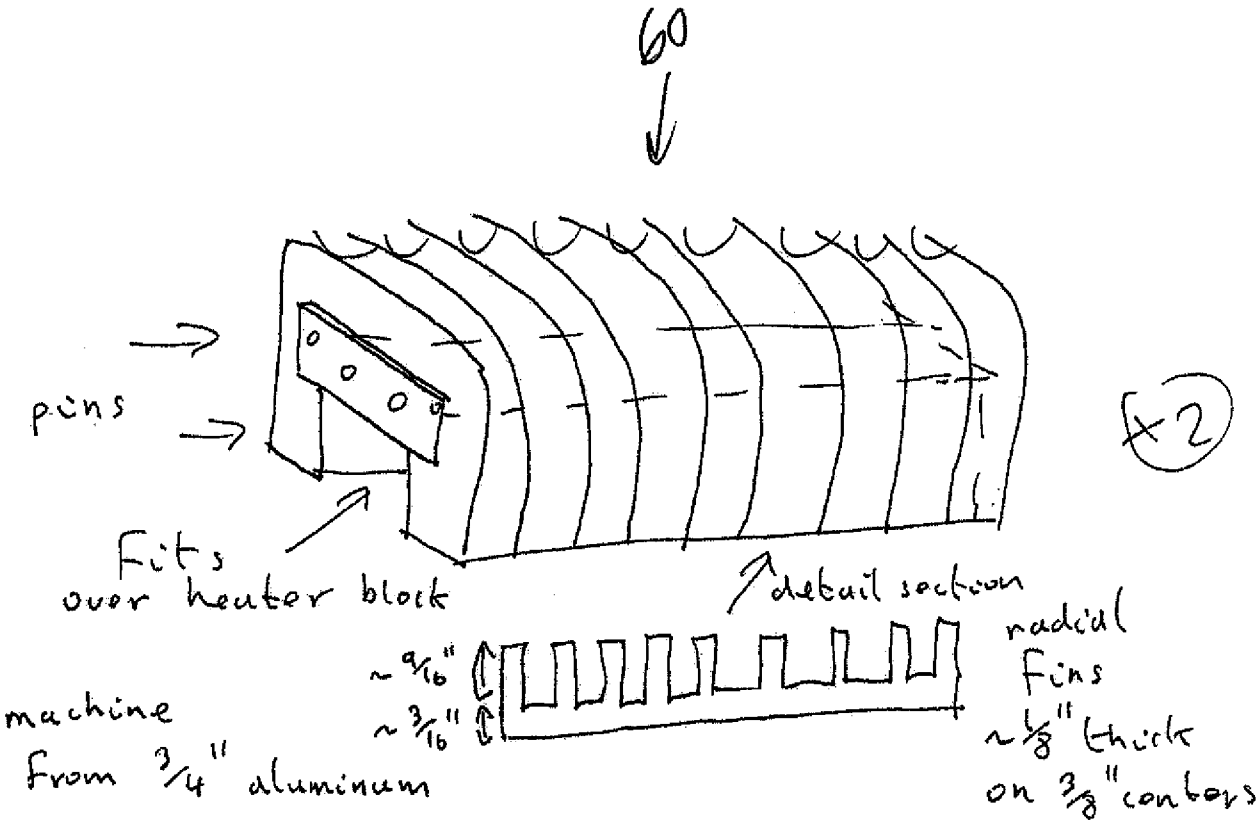


Fig. 8

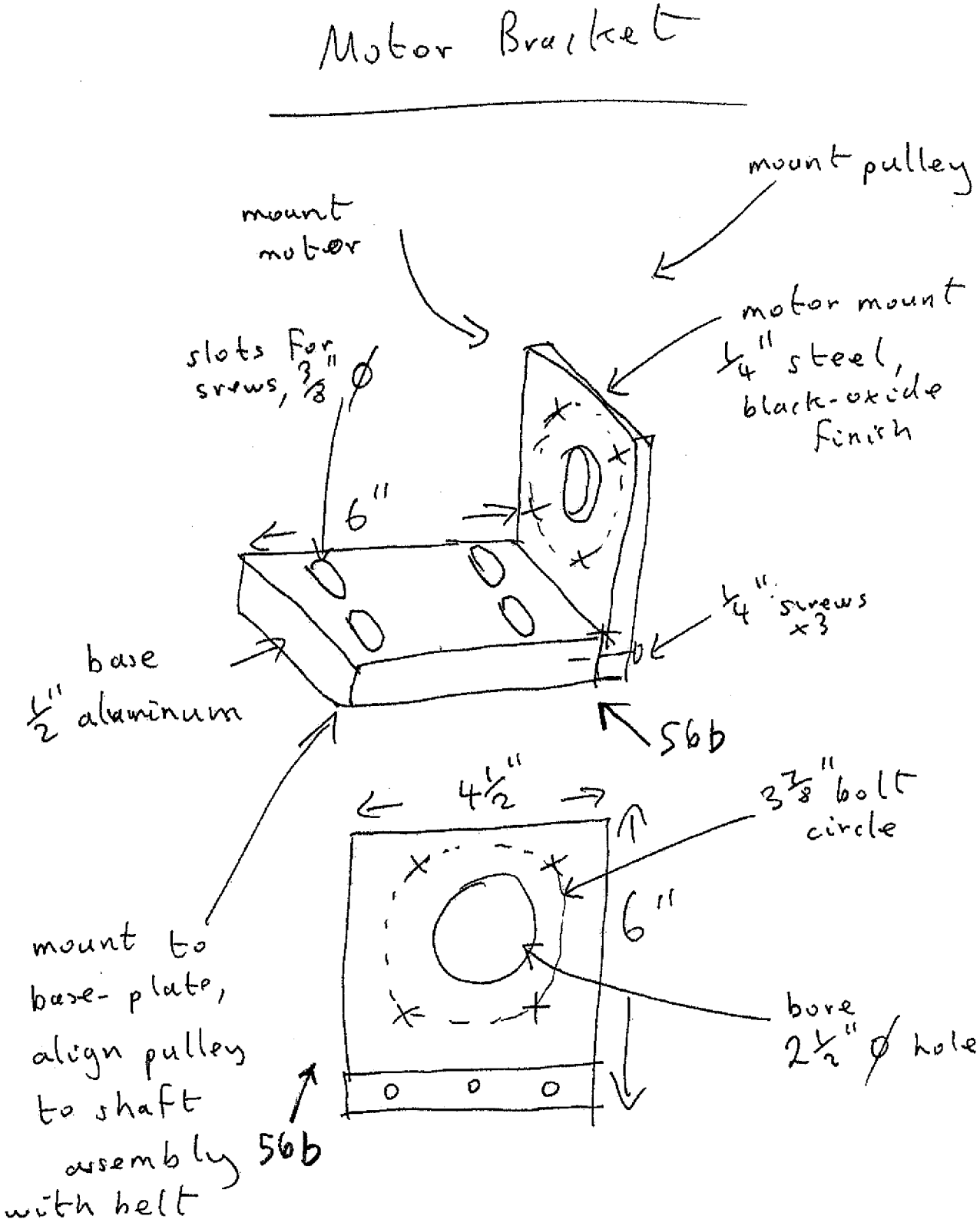

Motor Bracket
mount pulley
mount motor
motor mount
1/4" steel, black-oxide finish
slots For screws, 3/8" ∅
6"
1/4" screws x3
base 1/2" aluminum
56b
4 1/2"
3 3/8" bolt circle
6"
bore 2 1/2" ∅ hole
mount to base-plate, align pulley to shaft assembly with belt
56b

Fig. 9

Mercobac Mounting

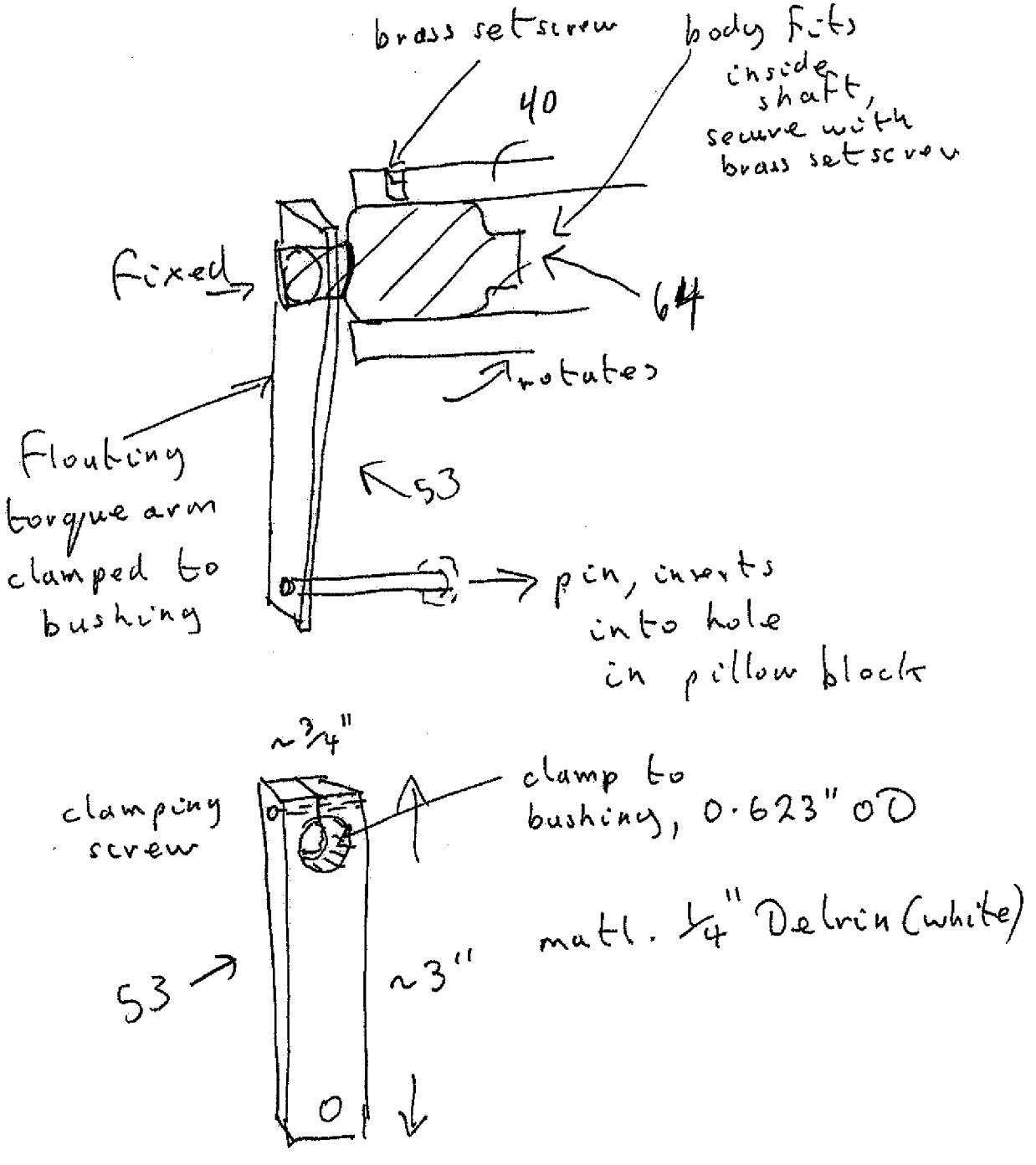


Fig. 10

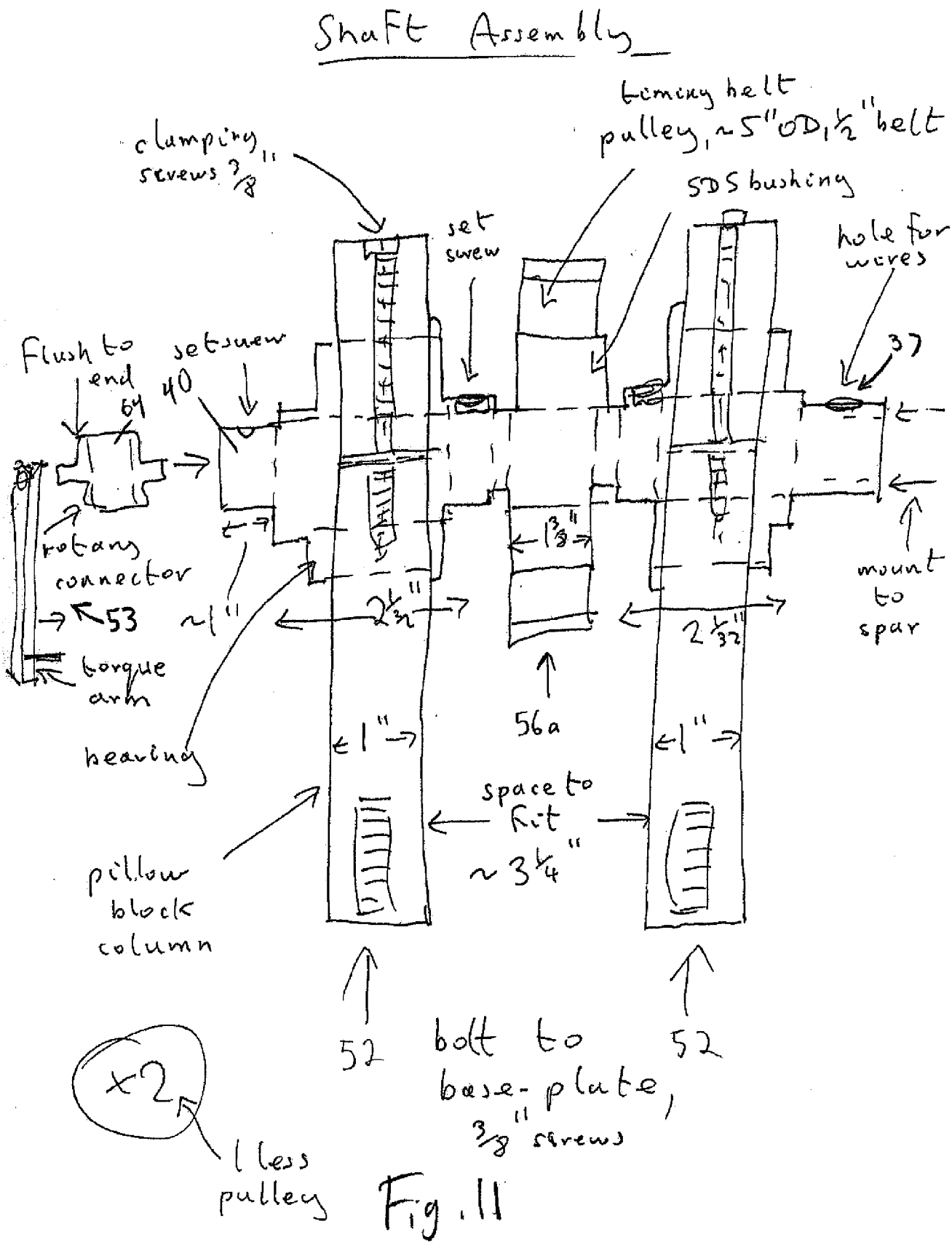

Shaft Assembly
clamping screws 3/8"
timing belt pulley, ~5" OD, 1/2" belt
SDS bushing
set screw
hole for wires
Flush to end
set screw
40
64
37
rotary connector
53
~1"
torque arm
bearing
1 3/8"
2 1/32"
2 1/32"
mount to spar
56a
1"
1"
space to fit
~3 1/4"
pillow block column
52
bolt to base-plate, 3/8" screws
52
x2
1 less pulley

Fig. 11

Mold Insert (two-piece)

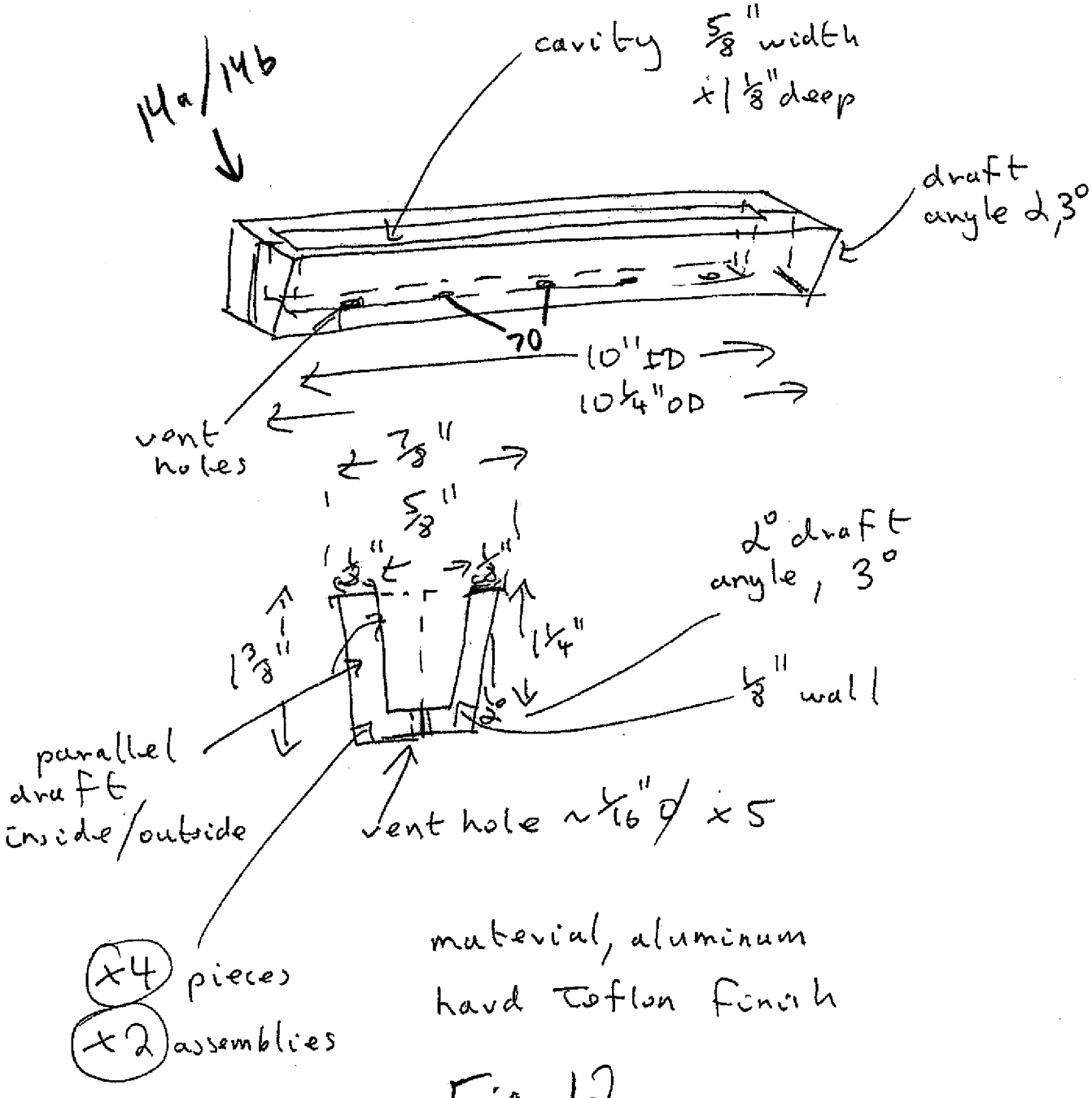
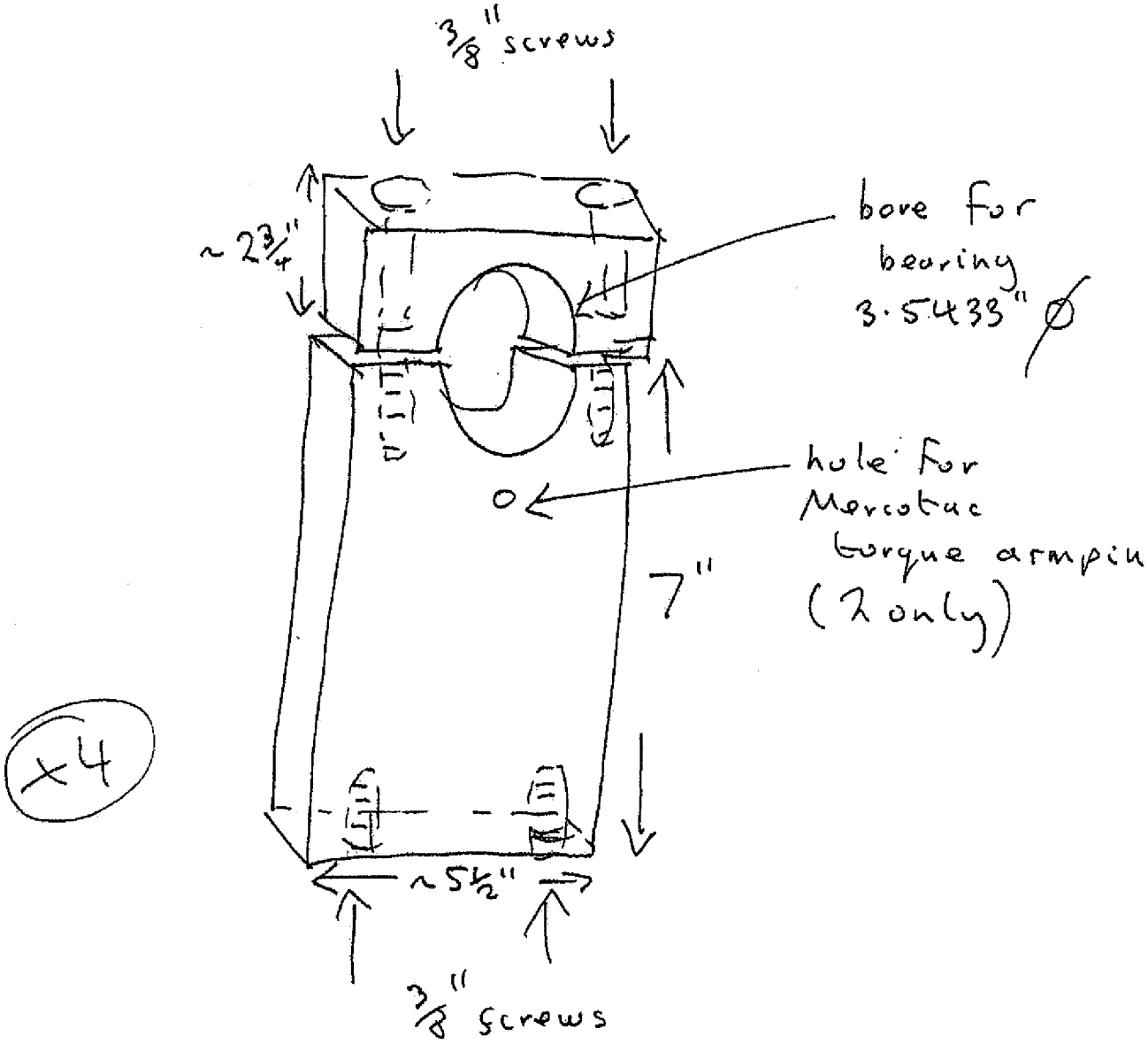


Fig. 12

Pillow Block



matl. 1" aluminum

Fig 13

Links / Locks

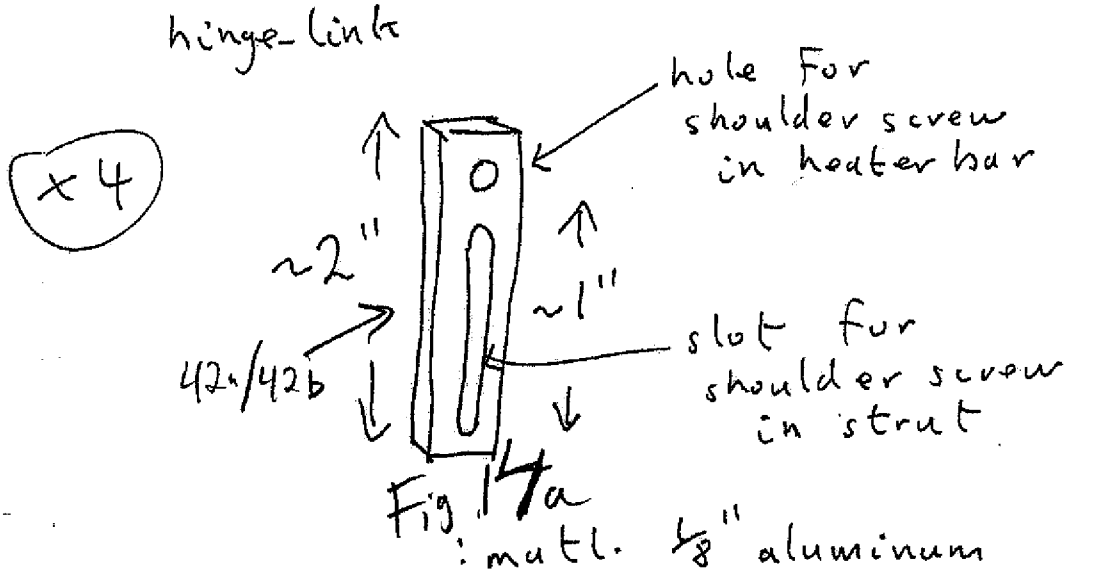
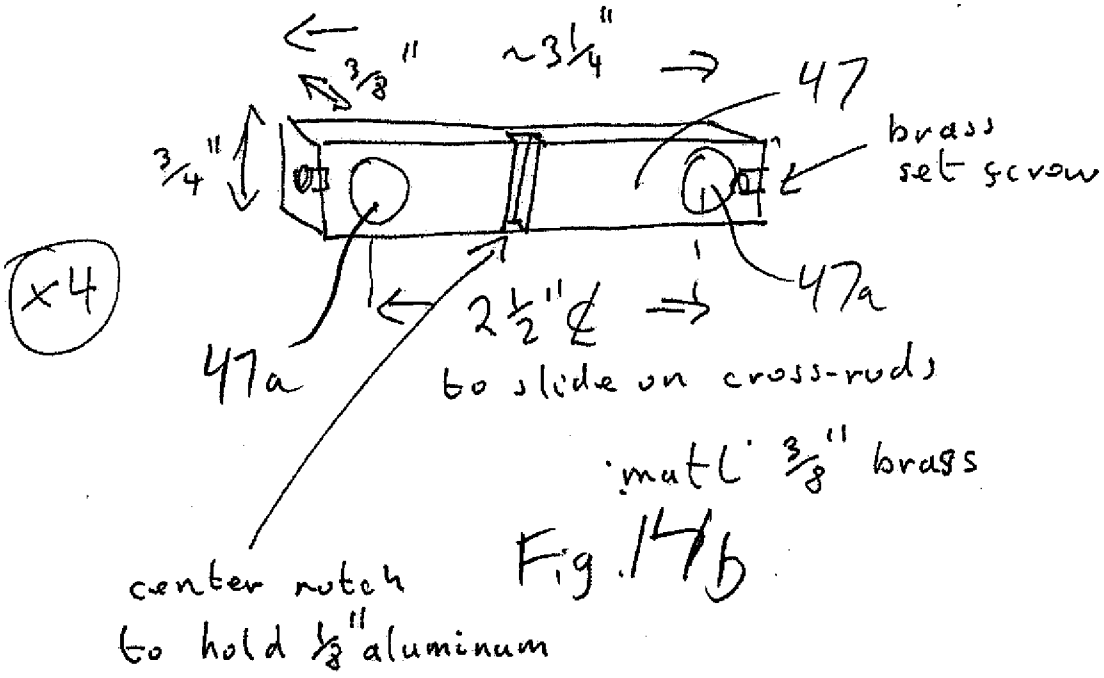


Fig. 14a

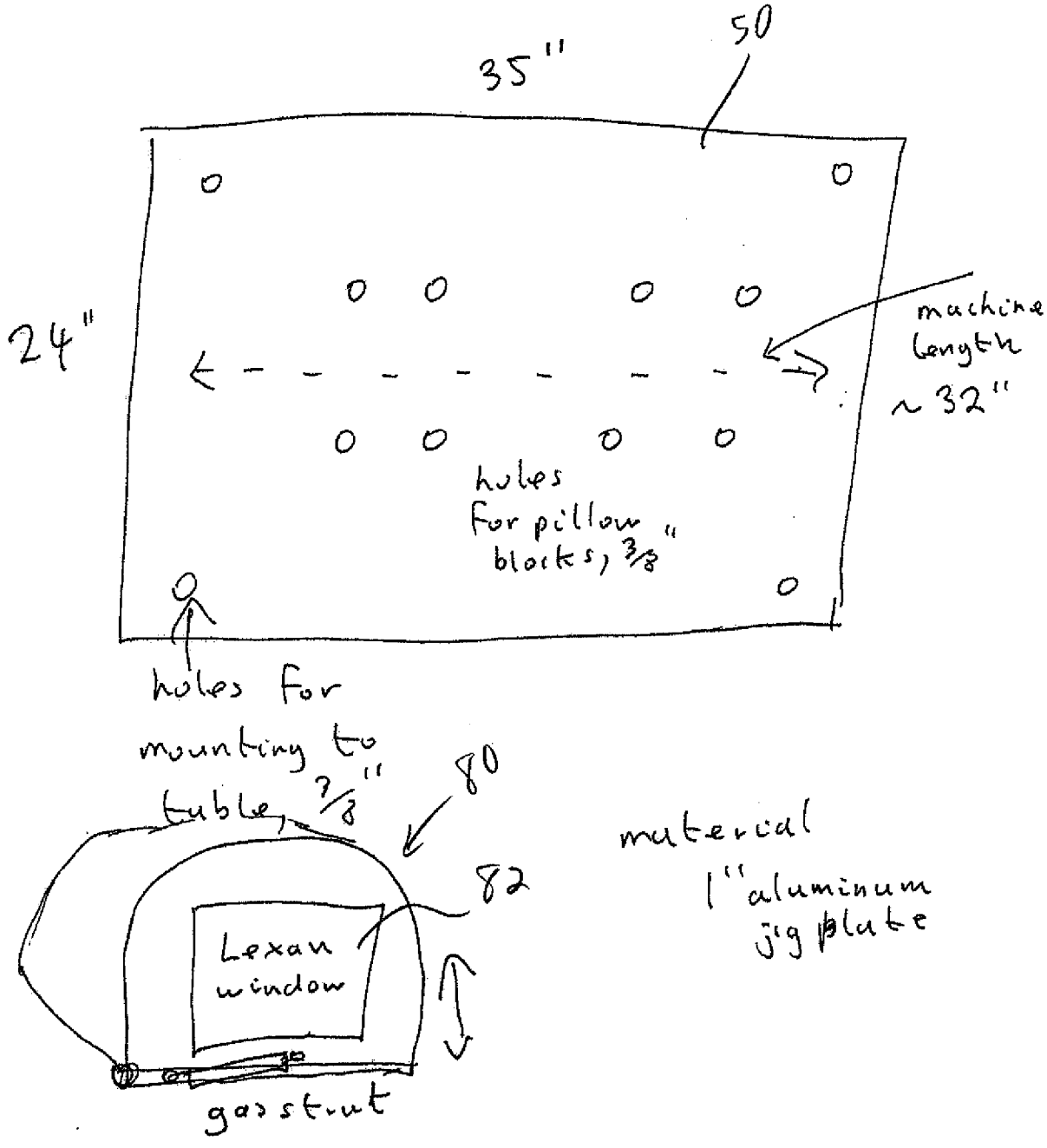
: matl. 1/8" aluminum



: matl 3/8" brass

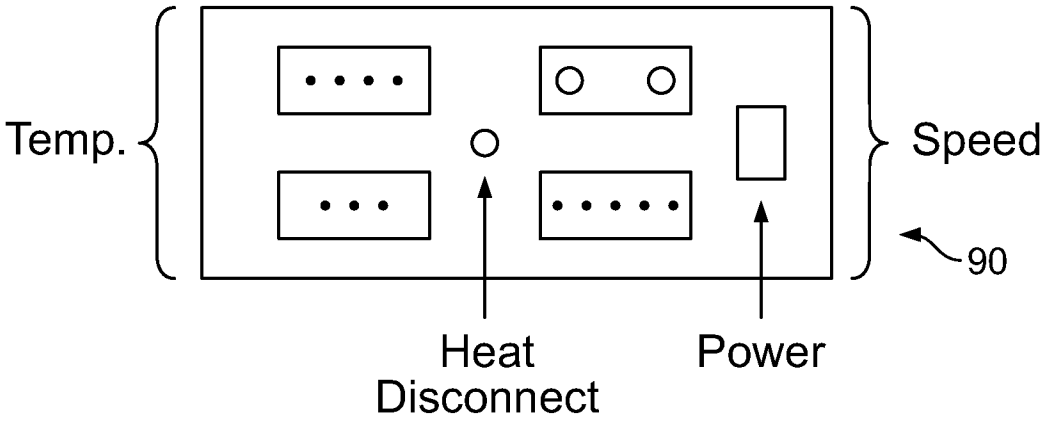
Fig. 14b

Base



safety cover, opens 90° Fig. 15

COTS Parts - Controls



Temp.	P/N	Qty.
PID Controller	MC 7981K82	2
Relay	MC 7456K14	2
Circuit Breaker	MC 3931T	1
Speed		
Motor Control	MC 7200K2	1
Tachometer	MC 8518T62	1
Sensor	MC 8518T96	1
Enclosure	Newark	1

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/020785

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B22D 13/02 (2013.01)
USPC - 525/29
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B22D 11/06, 13/00, 13/02, 25/04, 27/04; C08L 67/06 (2013.01)
USPC - 438/30; 523/500, 509; 525/29

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B22D 11/06, 13/00, 13/02, 13/023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patent Search, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,816,582 A (TENNYSON) 11 June 1974 (11.06.1974) entire document	1-23
Y	US 2007/0243649 A1 (BEARD) 18 October 2007 (18.10.2007) entire document	1-23
Y	US 2011/0189440 A1 (APPLEBY et al) 04 August 2011 (04.08.2011) entire document	2, 12, 22, 23
Y	US 5,837,171 A (DANZIK et al) 17 November 1998 (17.11.1998) entire document	3, 13
Y	US 4,766,163 A (STRUDWICK) 23 August 1988 (23.08.1988) entire document	4-6, 14, 15

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 February 2013	13 MAR 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)