SUPERHEATER TUBE TEMPERATURE MEASUREMENTS

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SUPERHEATER TUBE TEMPERATURE MEASUREMENTS

There has been a decided trend on boiler installations in the last few years to make extensive use of equipment for measuring superheater tube temperatures. What has brought about this trend? Are these measurements more important on boilers of current design than on boilers built ten years ago?

There are two fundamental reasons for this trend. First, the need for tube temperature measurements is generally greater, and second, instruments and techniques have been developed to make this type of measurement practical.

The trend toward the use of boilers with high capacities operating at high pressures and temperatures and the use of the reheat cycle is generally recognized. In a recent paper, it was brought out that the average utility boiler unit designed in 1951 by one boiler manufacturer was 975,000 lbs. per hour of steam at an average pressure and temperature of 1730 psi and 1005 F. The increase in average capacity was 50% in three years. The higher capacity has resulted in an increase of the physical size of the unit. The greater physical size has resulted in the need for measurements of temperature distribution across the unit.

The primary value of superheater tube temperature measurements is the knowledge gained of temperature distribution across the boiler. This information serves as a check on circulation through the tubes so that safe metal temperature will not be exceeded. Measurements may be taken by thermocouples installed on individual tubes near the superheater outlet header. These measurements not only assist in determining and testing the design of the unit and the proper location of soot blowers, but are also important operating guides in the use of blower equipment, and in determining the most suitable method of firing to maintain proper temperature distribution across the boiler.

Additional benefits may be obtained from these measurements. During start-up, tube temperatures indicate when water in pendent type superheater or reheater tubes has boiled out. There has been at least one instance where tube temperature measurements have indicated a flow restriction in one of the tubes. On some boiler designs, tube temperature measurements indicate excessive carry-over of water from the drums or excessive moisture introduced in desuperheating.

When this type of measurement was first attempted, the measuring equipment was not designed to be permanent. The results obtained were useful in design studies and in determining start-up procedures. Since the life of the measuring equipment was short, the measurements could not be used as an operating guide. One of the earliest comprehensive studies made on superheater tube temperature measurements was in 1932, reported in a paper by Arthur Williams of the Superheater Company presented by the Fuels Division at the annual meeting of the A.S.M.E. in December 1932.

It has long been recognized that a tube temperature measurement is not an easy measurement to make accurately. The metal temperature of the tube may be appreciably less than that of the surrounding hot gases. One of the simplest methods of obtaining this measurement is to attach a thermocouple to the outside of the superheater tube. The thermocouple leads must be carried through the high temperature zone (hot products of combustion) to the outside. Thus, these thermocouple leads will be at a higher temperature than the superheater tube, and will tend to conduct heat to the superheater tube at the point where the measurement is made. This conduction will distort the temperature measurement, causing an error known as a conduction error.

It was recognized early that the best means of reducing this error to a minimum was to bring the thermocouple leads away from the point of measurement at the superheater tube in a manner so that the temperature of the wires would approach the tube temperature, thus minimizing the conduction error. In early installations, the thermocouple wires were attached to the tube by means of peening. The tube was drilled to a depth of 1/16" and at a diameter slightly larger than the thermocouple wire. Two holes were made approximately 1/8" to 1/4" apart, one for each thermocouple wire. The thermocouple wires were then inserted in the holes and peened in. The wires were then wrapped around the tube for several turns in a manner to provide good thermal contact with the tube bringing the temperature of the leads in the vicinity of the measuring junction close to the temperature of the tubes and thereby minimizing the conduction error. Of course, it was necessary to electrically insulate these thermocouple wires from the tube. Mica was frequently used as insulating material and glass covered wire has been extensively used. In general, the wire size was kept small, approximately 18, 20, or 22 gauge to further minimize conduction errors.

This general method of making the tube temperature measurement was used in a number of installations for obtaining test data. Thermocouple wire size being kept small to minimize conduction errors resulted in a fairly short life of the thermocouple element.

Mr. C. G. R. Humphreys of the Combustion Engineering Company, in an article published in the December, 1944 issue of Combustion magazine, reported results of tests indicating that further protection could be applied to the thermocouple leads. Thin steel cover plates were installed over the thermocouple leads at the measuring junction to provide further protection. Since these plates were welded to the superheater tube, they provided good thermal contact between the cover plate and tube, thus maintaining the temperature of the plate and of the leadwire at essentially the same temperature as the tube and thereby minimizing conduction errors.

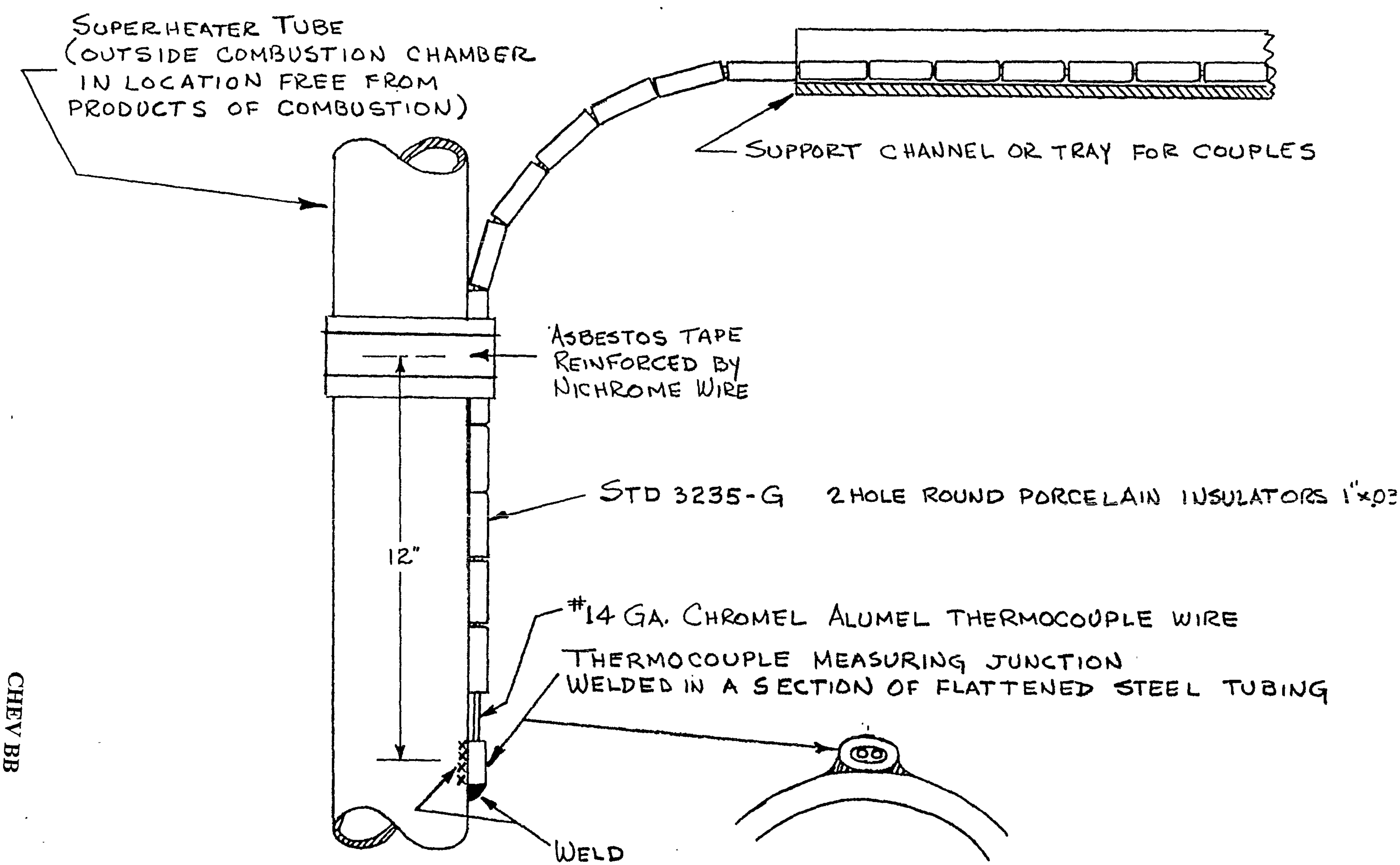
At the present time, many boilers are designed so that the temperature measurement of tubes entering the superheater or reheater outlet header may be made outside the combustion chamber of the furnace in the roof vestibule, or "doghouse", or the chamber between the furnace roof and boiler casing. In this general type of application, the temperature of the surrounding atmosphere approaches that of the tubes. In addition the atmosphere is relatively still, thus minimizing conditions tending to cause conduction errors. However, measurements are frequently made on elements actually within the combustion chamber, particularly on reheater tubes, to insure that safe temperatures exist during start-up.

These measurements on tubes within the combustion chamber present the greatest problems. It is apparent that the measurements must be carefully made to minimize thermocouple conduction errors which will be caused by the flow of the hot products of combustion past the thermocouple leads. In addition, for a reasonable length of life of the thermocouple element, the thermocouple must be protected from contamination by these hot gases which would result in a calibration shift and ultimate failure. A reducing atmosphere will contaminate chromel and alumel thermocouple wires, reducing the EMF output of the thermocouple for a given temperature measurement, and crystalize the metal causing ultimate failure. High sulphur content in the gases also contaminate the couple.

If measurements are only for test purposes of short duration, protection need not be provided. However, it has been found desirable on many units recently installed or currently being designed to provide tube temperature measuring equipment which can be used during operation of the boiler and which, therefore, must have long life.

The only satisfactory means of protecting the thermocouples from the hot products of combustion is to seal the couple from these gases. Not only must the couple be protected within the combustion chamber, but also in the chamber between the furnace roof and boiler casing, if there is any possibility that products of combustion may enter this section. This would certainly be expected on a positive pressure boiler. In addition, products of combustion may enter this chamber even on a negative pressure boiler. Certainly the furnace roof is not tight and a flow of combustion gases will take place in this chamber between any two openings where a pressure differential exists.

If the tube temperature measurements at the reheater outlet or superheater outlet are made in a section of the roof vestibule in which no products of combustion will be present, protection from the atmosphere is not necessary and unprotected couples may be used. Figure 1 illustrates one method of attaching a suitable couple to a tube where unprotected couples will be satisfactory. The thermocouple is made up of 14 gauge chromel and alumel thermocouple wire in 2-hole porcelain insulators 1" long. Note that the measuring junction is welded in a flattened section of steel tubing, which, in turn, is welded to the superheater tube. The welding insures good thermal contact between the thermocouple and the tube. To minimize conduction errors, it is good practice to tie the couple to the tube with asbestos tape reinforced with iron wire or nichrome wire for 12" to 18" from the measuring junction. It is expected that the atmosphere will consist of reasonably still air and that the air temperature will approach that of the tubes, thus making further precautions to minimize conduction errors unnecessary. Mechanical support of the thermocouples is required. Fourteen gauge couples are used as a compromise between the small size to minimize conduction errors and a large size to provide satisfactory mechanical strength. The thermocouples may be supported individually or a number of couples may be placed in a supporting channel or tray and brought



SUPERHEATER TUBE THERMOCOUPLE

FIG. 1

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through the boiler casing to suitable terminals. If no sharp bends are to be made in the thermocouple (less than a 15" radius), the 1" long, 2-hole insulators will be suitable for the entire length of the thermocouple. However, if short radius bends are to be made, fish spine insulators should be used on each thermocouple lead where the bend occurs.

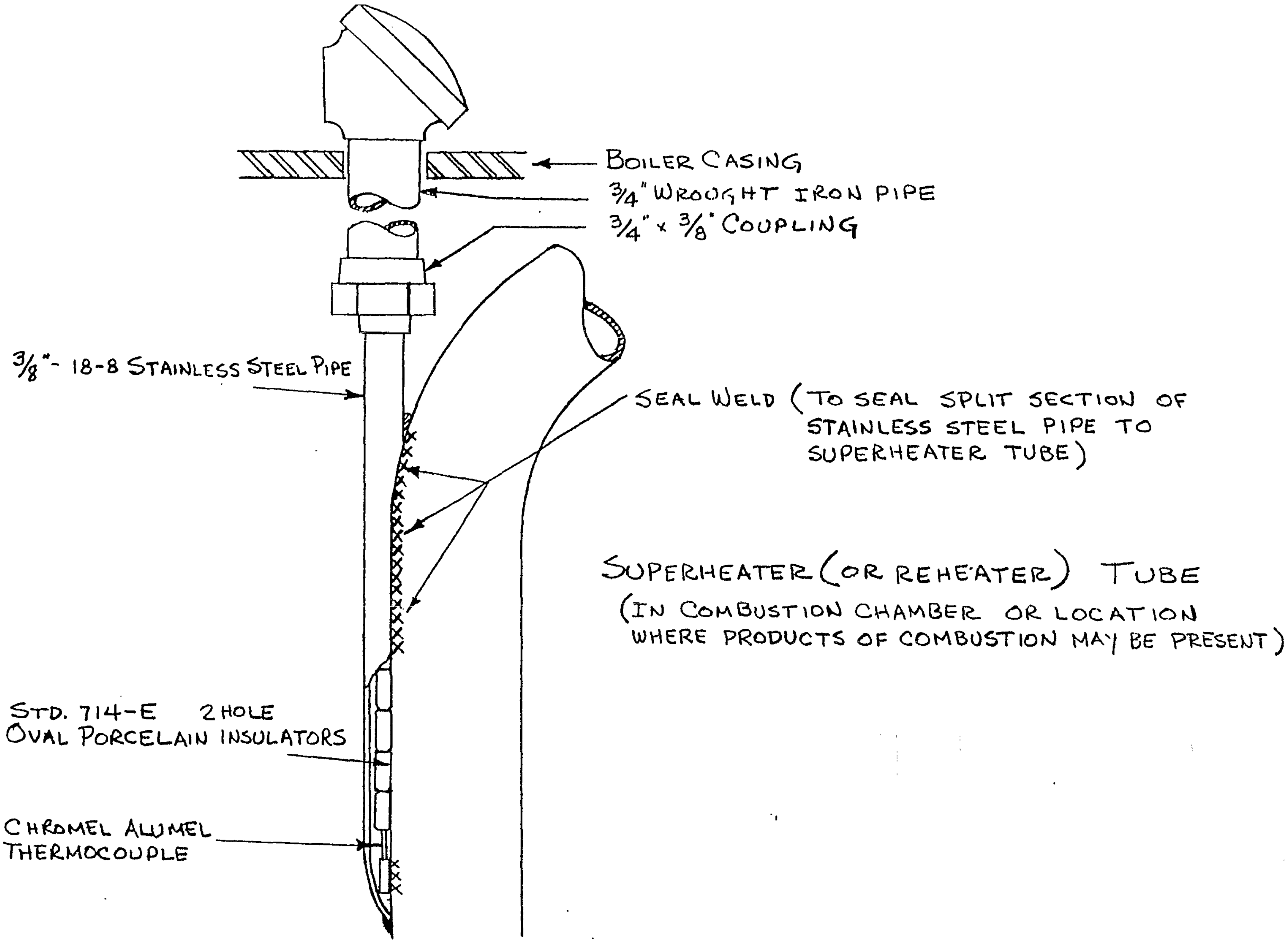
Twenty gauge glass insulated wire has been used for this type of installation. Where temperatures will exceed 1000 F, the glass insulated 20 gauge wire will not have as long a life expectancy as the thermocouple illustrated in Figure 1.

Chromel - alumel thermocouples are preferred for this application over iron constantan couples. For a given wire size, CA couples can withstand a higher temperature than I.C. In general for 14 gauge protected couples, the maximum temperature for CA is 2000 F, and for I.C. is only 1100 F. For a 14 gauge unprotected couple, the maximum for CA is 1700 F and for I.C. approximately 900 F.

As outlined previously, this method of measurement is not suitable if products of combustion are present in the atmosphere. Contamination of the couple will occur causing a change in calibration. Under these conditions, protection should be provided similar to that required for couples measuring tube temperatures within the combustion chamber of the furnace.

Figure 2 illustrates one method of making a measurement under these conditions. The thermocouple without the protection tube is basically the same as that illustrated in Figure 1. However, protection has been added to seal out the products of combustion. Note that the protection tube has been ground off on one side and welded to the superheater (or reheater) tube. This provides good thermal contact between the protection tube and the superheater tube, thus bringing the protection tube temperature and thermocouple lead temperature close to the superheater tube temperature. This minimizes the conduction error. The mass of the protection tube is relatively small so that the temperature of the superheater tube is not appreciably changed by the addition of this couple. The protection tube is 3/8" 18-8 stainless steel pipe where it is exposed to the flow of the hot products of combustion. However, in the roof vestibule or "doghouse", the atmosphere temperature is considerably lower and 3/4" wrought iron pipe is suitable. The basic purpose of the protection tube is to protect the thermocouple from contamination by the hot products of combustion. The protection will be no better than the seal provided by the seal weld. In general, it is most suitable to grind the protection tube in the field to suit the contour of the superheater or reheater tube.

Figures 3 and 4 illustrate alternate methods which have been used to make this measurement. Each of these two methods enables the use of a simpler weld to seal out the hot products of combustion. However, each has the limitation that it does not provide as good thermal contact between the protection tube and the superheater tube element as the arrangement shown in Figure 2. It is expected that the conduction errors will be greater. Most of the heat picked up from the hot gases by the thermocouple protection tube is conducted to the superheater element in the vicinity of the measuring junction of the thermocouple thus raising the temperature at this point. In the arrangement



SUPERHEATER TUBE THERMOCOUPLE

FIG. 2

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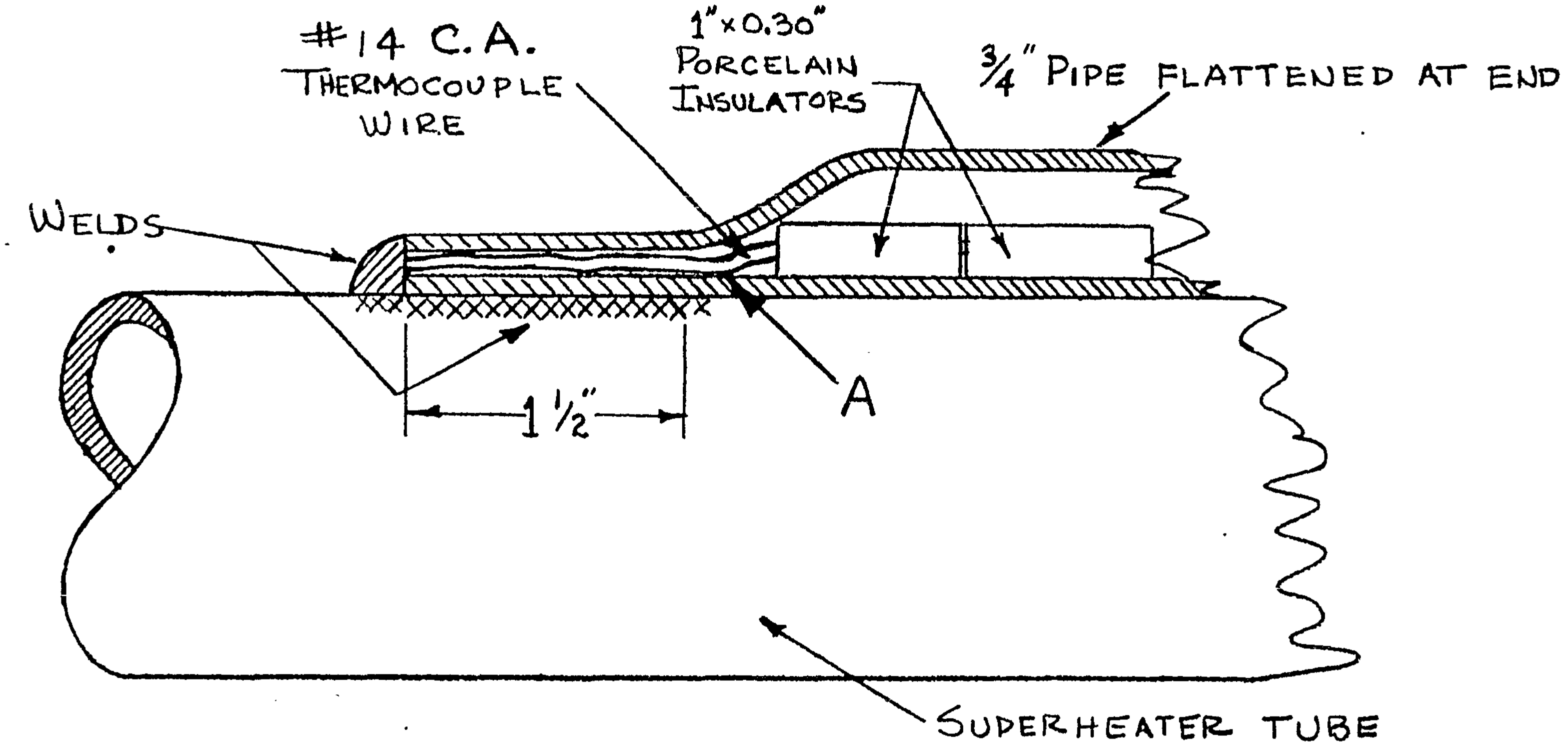

SUPERHEATER TUBE THERMOCOUPLE

FIG 3

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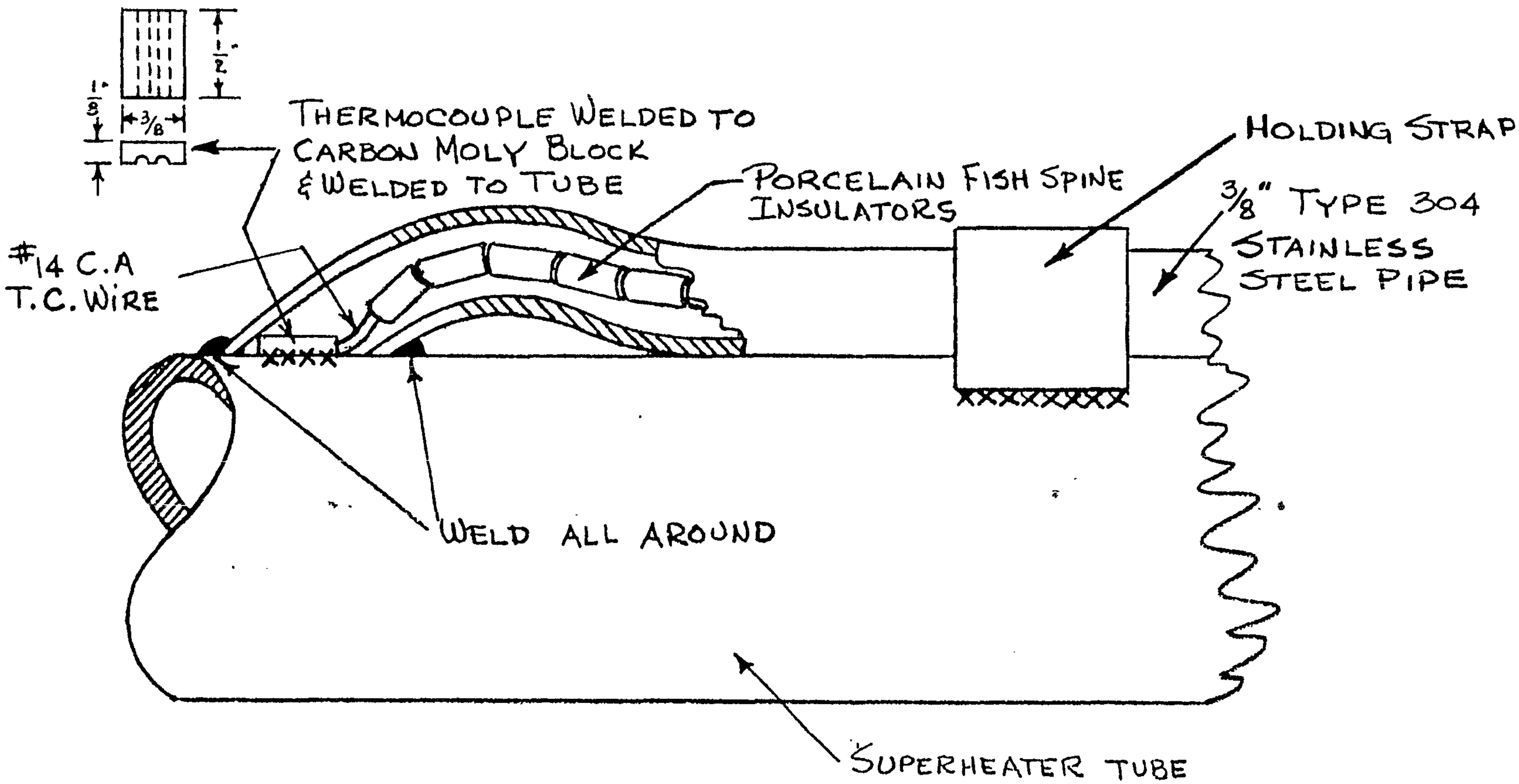

SUPERHEATER TUBE THERMOCOUPLE

FIG 4

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shown in Figure 3, the actual measuring junction is at *Point A. The conduction* error could be reduced by the use of a 3/8" pipe protection tube instead of 3/4", and by extending the weld of the protection tube to the superheater further along the tube. Although the thermocouple protection tube and the superheater element may apparently be in close contact, actually the contact is only a series of point contacts, or line contacts, and is not efficient from a heat transfer standpoint. Welding one to another provides good thermal contact.

The conduction errors cannot be accurately estimated and may or may not be appreciable. Some of the factors influencing the magnitude of this error include the following:

1. The temperature difference between the hot products of combustion and superheater element.
2. The mass of the protection tube relative to that of the superheater element.
3. The rate of heat transfer from the hot gases to the thermocouple protection tube.
4. The velocity of the hot gases.
5. The velocity of the steam flow through the superheater element.

In the face of the unknown, with so many variables, it is felt that steps which can be readily taken to minimize the conduction errors are justified.

One of the major limitations of this type of measuring element is the difficulty or impossibility of replacing the element. This limitation does not apply to the unprotected thermocouples illustrated in Figure 1. Of course, where replacement presents a problem, the obvious answer is to design the thermocouple and its installation so that reasonable life of the thermocouple may be expected and replacement becomes unnecessary.

In this connection, protection from contamination by the hot products of combustion has been discussed. In addition, the thermocouples should be protected from excessively high temperatures which would exist if the thermocouple and its protection tube extended for any appreciable distance through the hot products of combustion. It has been brought out that a 14 gauge chromel - alumel couple would not be expected to last long at temperatures greater than about 2000 F. Accordingly, it is good practice to keep the thermocouple and its protection tube adjacent to, and in contact with, the superheater tube element where this thermocouple is brought through the hot products of combustion. This will provide a "cooling" of the thermocouple by the superheater tube.

Some attempts have been made to design a thermocouple for this application which might be easier to replace. In each case, either some sacrifice has been made by reducing the protection and shortening the life of the couple, or by increasing the possibility of conduction errors. The mass of the thermocouple and its protection tube at the location of the measuring junction must be kept reasonably small to minimize conduction errors, and should be in closest possible thermal contact with the superheater tube. Proper protection and proper installation will eliminate the need for replacement.

In this connection, some experience has been obtained indicating that proper installation will provide satisfactory life. In one installation made two years ago, approximately 5% of the thermocouples failed in the first few months of use. Since that time, however, there have been no additional failures. This can indicate that the early failures were caused by improper protection, and those thermocouples adequately protected have not failed. The thermocouple installations were generally of the type illustrated in Figure 1 and in Figure 4. Of course, those thermocouples of the type shown in Figure 1 were installed where the atmosphere was still air.

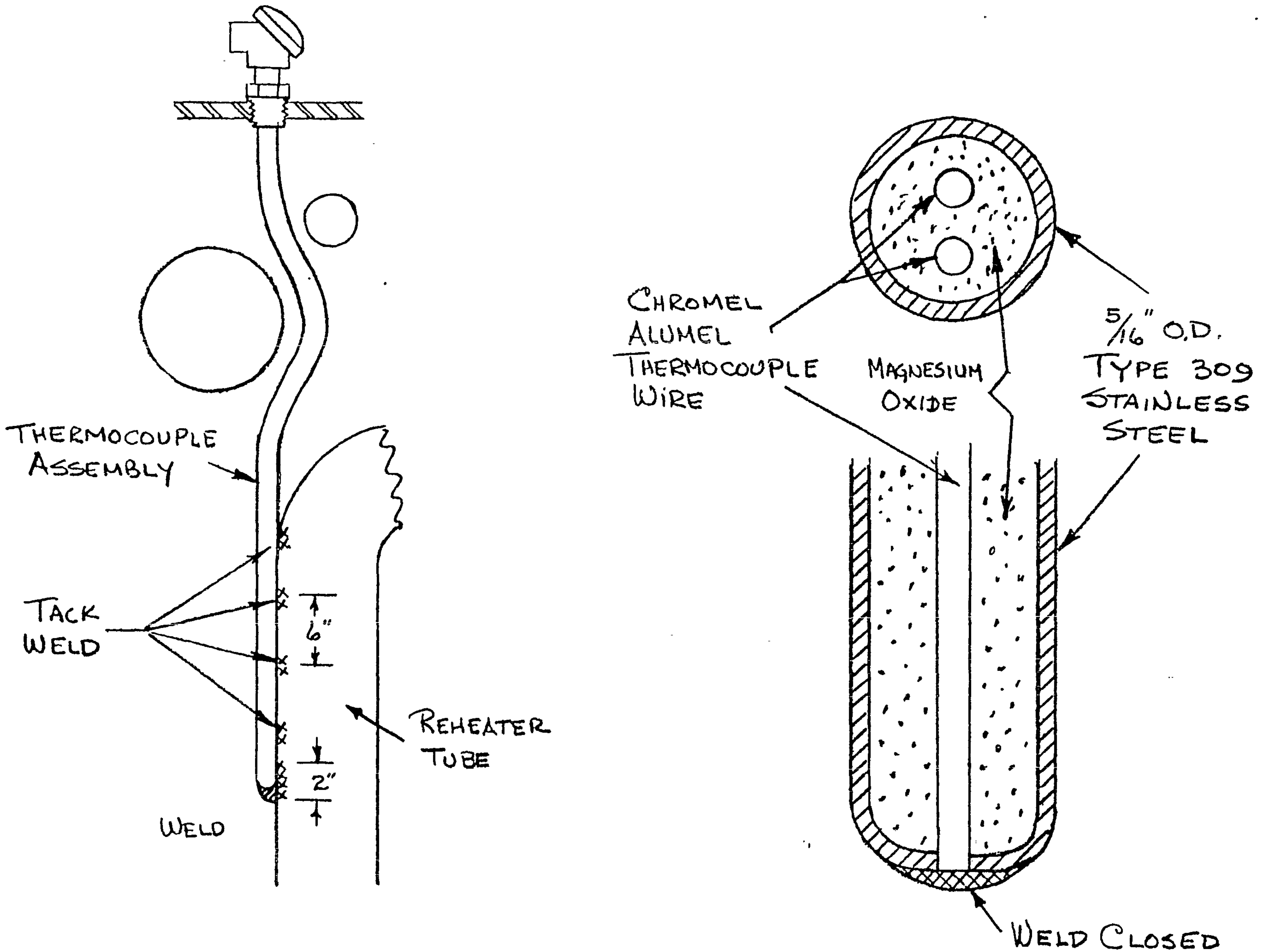
Somewhat similar results were reported in another installation, where the percentage of early failures was near 20%. Here, the thermocouples were generally similar to those shown in Figure 2 except that the couples were peened to the superheater tubes and alundum cement was used to seal the thermocouple at each end of the protection tube. An inadequate seal would result in an early failure whereas a satisfactory seal would result in an indefinite life. Since all the failures occurred early in their use, it is expected that failures resulted from an inadequate seal. It is felt that a real seal will furnish indefinite protection.

The cost of these measuring devices includes not only the cost of the thermocouple assembly, but also the cost of installing the assembly. Development work is being made with a view toward reducing overall cost without any sacrifice in accuracy of measurement or life expectancy. Since the general theme of this meeting is "With an Eye to the Future", it may be pertinent to describe a thermocouple assembly which is expected to reduce the installation cost and to be better protected.

Figure 5 illustrates a swaged type thermocouple. The particular assembly illustrated, consists of a chromel - alumel thermocouple encased in magnesium oxide enclosed in a 5/16" O.D. type 309 stainless steel sheath. The measuring junction is welded to the closed end of the sheath. This swaged type construction is similar to that employed in the electric heating elements of domestic electric stoves. This type of construction provides a thermocouple element that is sufficiently flexible so that it may be bent around obstructions. It should be noted that the element is welded to the superheater tube for a distance of approximately 2" from the measuring junction and tack welded at approximately 6" intervals along the rest of the superheater tube where the thermocouple element is maintained in close proximity with the tube to prevent overheating from the hot gases. The field welding has no bearing on the efficiency of the seal of the thermocouple against the effects of the hot products of combustion. Thus, the technique of the field welding should not affect thermocouple life.

It is expected that the installation cost of such a thermocouple element will be considerably less than for a thermocouple of the type illustrated in Figure 2. This cost reduction would be made possible in view of the following:

1. The element is sufficiently flexible to facilitate bending in the field to clear obstructions in the roof vestibule or "doghouse".



SUPERHEATER TUBE THERMOCOUPLE
FIG. 5

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2. Less engineering and drafting time will be required to detail the construction and design of the thermocouple to clear obstructions.

3. The field welding costs may be somewhat less.

4. Grinding the protection tube to the contour of the superheater element is eliminated.

5. Since the efficiency of the protection is independent of field welding, a higher percentage of permanent couples is expected.

6. These thermocouples may be provided with a compression type fitting to facilitate their exit through the boiler casing. On positive pressure units, this will provide an effective pressure seal.

7. In view of the relative flexibility, it may be possible to group a number of elements to go through the boiler casing at one location.

These advantages may be gained with no sacrifice in the basic function of the thermocouple to measuring temperature accurately. Conduction errors are expected to be as low or lower than the arrangements previously shown. Sealing at the factory against the hot products of combustion will insure longest possible life.

There may be some limitations to the extensive use of this type of thermocouple assembly. At the present time, it is expected that the cost of the individual thermocouple elements may be somewhat higher than the cost of elements shown in Figure 2. However, the installation cost is expected to be less. Furthermore, mass production may result in an appreciable lowering of this cost. At the present time, manufacturing techniques have not been devised to permit construction of this type of element in a length longer than 15 ft. for the 5/16" O.D. element illustrated. Further development work is in progress to increase this length. Consideration is being given to means of joining sections which will permit longer elements.

Swaged type thermocouples can be provided in diameters larger and smaller than the 5/16" O.D. shown. However, this size is felt to be a reasonable compromise considering conduction errors, flexibility, and long life. The thermocouple assembly should be protected from the high temperatures of the products of combustion by maintaining reasonably close contact between the thermocouple assembly and the superheater element in the combustion zone. It is estimated that approximately 1500 F will be the maximum temperature which this couple can withstand with a reasonable length of life. This maximum temperature would depend upon the size of element used. It is felt that, as with other type elements, some slack or allowance should be made for expansion between supports of the couple.

Up to this point, only the primary element design and application have been discussed. The other end of the thermocouple leads, the measuring instrument, is just as important.

It has already been brought out that the measurements are useful not only for initial start-up, but also for start-up after every shut-down and more particularly for day to day operation. To obtain maximum benefit from tube temperature measurements and to provide a complete picture of temperature distribution, a large number of measurements are required. Accordingly, a measuring instrument must be designed to accommodate a large number of primary elements.

From plant to plant, operating procedures differ widely with regard to tube temperature measurements. In some plants, these measurements are continuously recorded, while in other plants the measurements are indicated only (or are periodically recorded for a log). Some plants rely primarily upon alarms to indicate when preset temperatures have been exceeded. Accordingly, the measuring instrument must handle a large number of measurements and with a degree of flexibility to meet these different operating requirements.

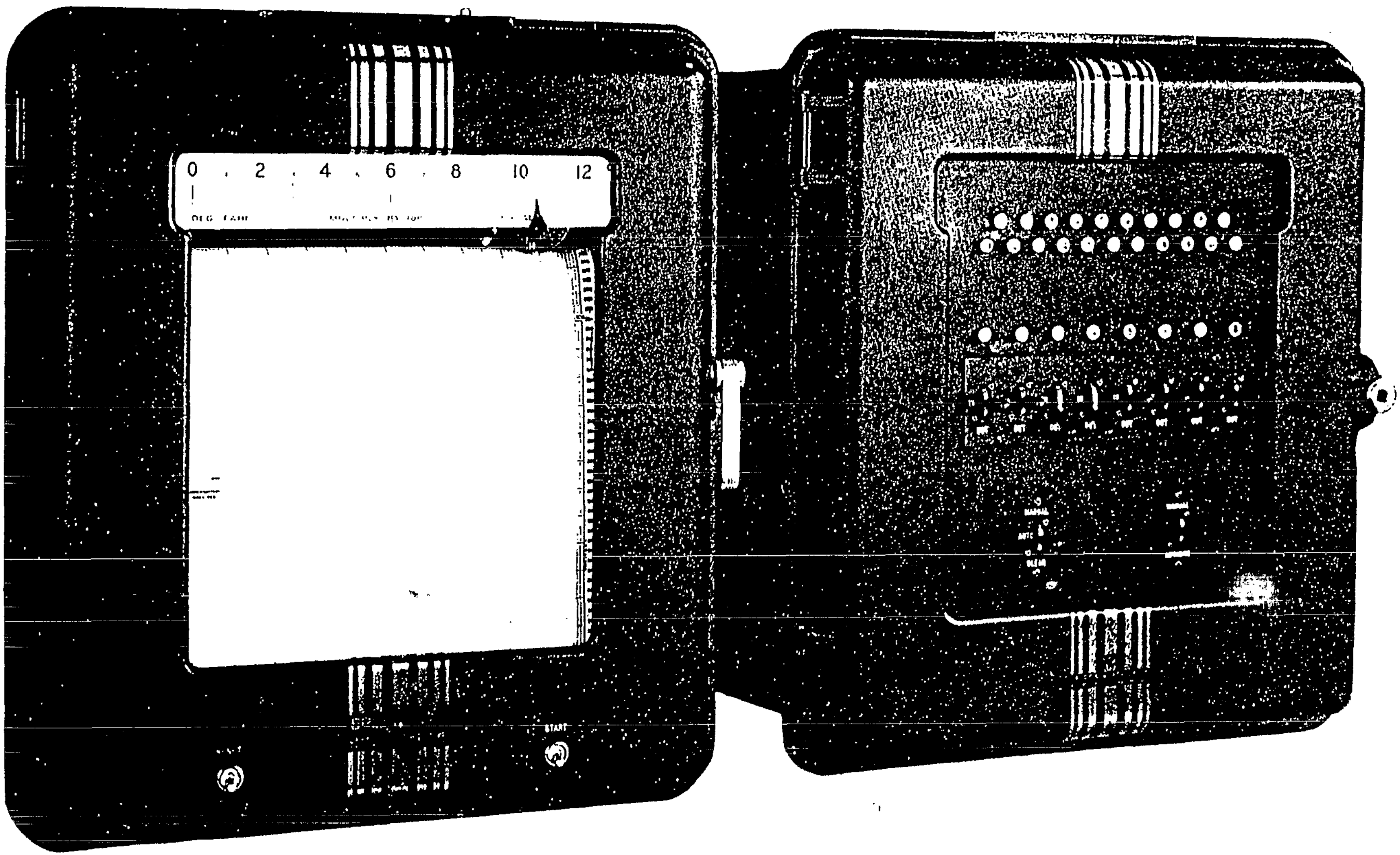
Figure 6 illustrates a multi-point, multi-bank type scanner assembly. Basically, the instrument consists of two components.

1. The indicator and recorder assembly.
2. The switch unit with indicating lights to identify the thermocouple measurement currently being made.

The switching unit is normally arranged in banks, or groups, of twenty thermocouples, with as many as eight banks being handled by one switching unit. One signal light indicates the particular bank on which measurements are being made, and other signal lights indicate the particular element within that bank on which the measurement is being made. This switching unit also includes switches to permit complete banks to be cut into service or out of service as selected. In addition, switches are provided to permit any one thermocouple to be manually selected and continuously measured.

A description of a typical method of operation may indicate some of the flexibility of this type of instrument. In many plants, a full complement of 160 points are indicated successively without being recorded. The indicator shows the temperature, and the signal lights on the switching unit indicate the point of measurement. A switch is provided on the door of the indicator to start the instrument recording and recording can be stopped at any time by operation of a switch. Thus, periodically it is possible for the operator to "log" the temperatures.

In addition, the typical installation includes a number of alarms, frequently one alarm associated with each bank of twenty thermocouples. In this typical installation, whenever any one point exceeds its alarm setting, not only is the alarm actuated, but the recorder will automatically start recording. The record starts with a measurement of the point which actuated the alarm and all successive points until the recorder is manually stopped.



160-POINT TEMPERATURE SCANNER

FIG. 6

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The standard speed of operation is four seconds per point. Faster speeds are available when required, and instruments have been provided with a faster speed. The maximum number of points which can be accommodated by a single switching unit is 160 points (eight banks of twenty points each). Many instruments have been provided with less than eight banks as required by the particular installation. In addition, there have been some installations where more than one switching unit has been used, thus providing coverage for more than 160 points. Instruments have been furnished with as high as 840 points being scanned.

In a typical installation, it is usual to find a particular bank or banks devoted to measurements of tube temperatures at the superheater outlet, with other banks devoted to measurements on reheater tubes within the combustion chamber of the furnace. Frequently, a bank has been used for measurements of miscellaneous drum temperatures, and other temperatures particularly useful during start-up, but not necessarily used in routine operation. Thus, this particular bank of measurements might be cut out during normal operation permitting the remaining points to be scanned more frequently.

There are a number of installations of this type of instrument where each bank of thermocouple measurements has associated with it a separate remote reference junction box. This facilitates orderly grouping of thermocouple leads at the boiler to permit the use of copper leadwire instead of thermocouple leadwire back to the instrument. One large reference junction box would still require a large quantity of compensating leadwire from the couples to the junction box on a large unit.

The flexibility of this type of instrument may be further illustrated. For many installations, it has been furnished with more than one temperature range. For example, one range of 0-1200 F for chromel - alumel thermocouples has been provided for tube temperature measurements, and another range, 0-400 F for copper constantan thermocouples has been provided for bearing temperature measurements. Thus, this one instrument may serve to monitor not only tube temperature measurements but also miscellaneous bearing temperatures.

In the relatively short time since this instrument has been developed, nearly 100 of these scanners have been purchased for the central station. It is interesting to note that over 60 of these instruments are for the purpose of making tube temperature measurements. Already tube temperature measurements have been considered to be practical for at least this many units.

It is hoped that this discussion has indicated that tube temperature measurements are practical wherever there is a need for such measurements. As outlined, a correctly designed thermocouple assembly, properly installed, will provide a dependable measurement not only for test purposes, but also for an operating guide. It is believed that the technique has been developed and the proper instrument is available to make this a practical measurement.