THE INSTITUTE OF ENERGY
MIDLAND SECTION

MODERN PRACTICE IN REHEATING AND HEAT TREATMENT FURNACES

UNIVERSITY OF ASTON IN BIRMINGHAM

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THE REALITY OF HIGH TEMPERATURE FURNACE DESIGN

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THE INSTITUTE OF ENERGY - MIDLAND SECTION

ONE DAY SYMPOSIUM

MODERN PRACTICE IN REHEATING AND HEAT TREATMENT FURNACES

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THE REALITY OF HIGH TEMPERATURE REHEATING FURNACE DESIGN

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INTRODUCTION

The design of reheating furnaces is influenced by many factors, and fuel efficiency and ideal optimised design may have to be sacrificed to the realities of capital cost, site restrictions, production requirements, and reliability.

Some of these 'realities' often turn out to be short-sighted and expensive errors of judgment which ultimately require drastic action to recover the situation. The factors which need to be considered can make for a very delicate balance between correct and incorrect design and it must be admitted that sometimes the users are influenced by extravagant claims made by furnace designers. These claims are quite often very difficult to justify, being based completely on theory rather than practical engineering experience.

In compiling this paper three installations have been considered which illustrate many of the 'realities' which can be encountered. The first two are continuous furnaces for billet heating and in both cases operating experience showed that they required to be radically altered from the original concept. The first suffered mainly from maintenance problems causing great expense and loss of furnace availability, the second had a lack of quality heating causing material rejection. In both cases the major problems have been overcome but at a high price compared with the cost if they had been originally installed in their 'todays' form.

The third installation is a batch furnace complex for a forge where Titanium ingots are heated to close temperature tolerances with the furnace atmosphere requiring to be guaranteed as oxidizing. Traditionally these furnaces have been electrically heated since the possibility of hydrogen pick-up from the furnace atmosphere was considered to be too much of a risk with gas or oil firing. At temperatures in the range of 1150°C. electrical element life was very problematic. The saving in maintenance costs and furnace down time has more than justified this risk and three furnaces have now been installed and proven. Here the new furnaces had to fit a site laid out for electric furnaces, severely limiting the basic design options.

Two Contrasting Billet Mill Furnace Installations

These installations have been altered from their original concepts, to give better performance. One has been simplified, the other made more complex, in both the furnace design has had to adapt to the reality of production demands, site restrictions and cost.

South Africa This serves a continuous rod and bar mill, working to close tolerances, with outputs in the range 25-70 tonnes per hour, using 5½" square x 24' 0" long 'concast' billets. Originally, there was a large Walking Beam 2 zone top fired furnace, heating the billets to rolling temperature (1200°C.), which left the Roughing section as 4" square x 48' 0" long billets. These should have passed directly to the Finishing section, but loss of temperature uniformity compelled the introduction of a second furnace, for 'equalising' the temperature at 1200°C. The billets had to be cut to 24' 0" long for this furnace, which was a side charged, side discharged pusher type, top fired. The diagrammatic layout is shown in Fig. 1, as installed in 1967.

Fuel is hot detarred producer gas, C.V. about 175 B.t.u/ft.[3] The reheating furnace was easily rated, designed for 60 T/Hr., with the billets charged through an open end, and discharged sideways on water cooled rollers within the furnace, being conveyed through on four beams. Maintenance costs were high, and there was a need for 70 + tonnes per hour output frequently, which the furnace could not meet.

First, the output was increased by enlarging the heating zone, and adding burners towards the charge end, firing opposed to the main burners. This placed more heat where it could be effectively used, and increased the output to 70 + tonnes/hour, with a small decrease in efficiency. To avoid costly alterations, this new 'zone' used cold combustion air, leaving the existing combustion system unaltered. A by-pass flue was put around the recuperators in case the increased waste gas volume caused overheating. The alteration was installed at Christmas shutdown 1973, at relatively small cost and worked quite well, enabling the mill's output potential to be better utilised.

Next, the equalising furnace was replaced with a new furnace taking 48' 0" long billets, instead of 24' 0" long. This achieved better yield from the mill, by halving the number of 'ends', and made larger coils of rod possible.

The design of the new furnace had to overcome a space problem. The Mill and furnace are on a mezzanine floor, above ground level, which ended just past this furnace, preventing the use of a larger furnace of the existing design. The cost of extending the floor was prohibitive, and the only solution was to end charge the furnace, with the billet transfer table in line, posing the problem of making a furnace with a 50' 0" wide charge opening, with a very short length, and getting even waste gas take off with minimum heat loss from the charge doors.

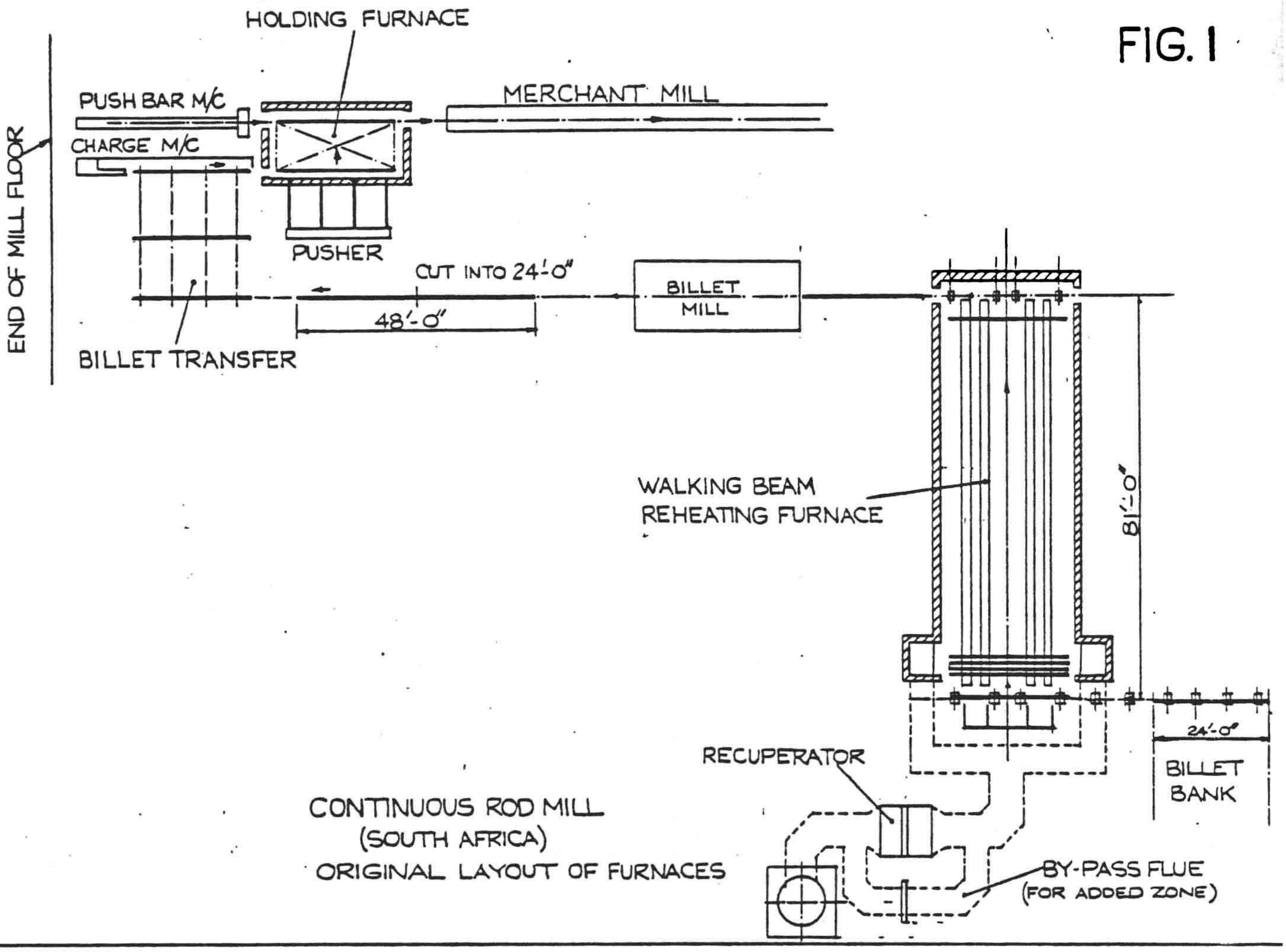
The concept was just about the worst possible, dictated by the reality of the site. As built it is simpler than the previous furnace, with the billets being pushed into and down the furnace by pusher fingers working within the transfer table. This eliminates the side charging machine and water cooled pusher fingers used previously, and a simple push bar machine is used to discharge the billets. The waste gas flues are on top of the furnace, and with the end doors are supported on a large 'Warren' truss across the width of the furnace. The original instrumentation, combustion controls and burners were retained, but a new ejector type chimney was fitted.

This furnace does very little 'heating', and has a relatively low fuel consumption, at a fairly constant rate. With a high waste gas temperature, about 1100^{o}C. it should have recuperation fitted. This was not done, because of cost restraints and the low fuel cost. The installation, including demolishing the old furnace was done in 4 weeks, again at the Christmas shut down in 1974.

Lastly, the reheating furnace was built as a pusher type furnace, in 1976. The charge end was closed, and the billets side-charged, with a finger type pusher working through the end wall, and side discharged with a push bar machine. The waste gases are exhausted at the end and pass under the billets, giving some under heating to minimise 'bowing' of cold billets when charged, which can be troublesome with long billets. The combustion arrangements remain unaltered, and the redundant beam operating hydraulic equipment was utilised to work the pusher.

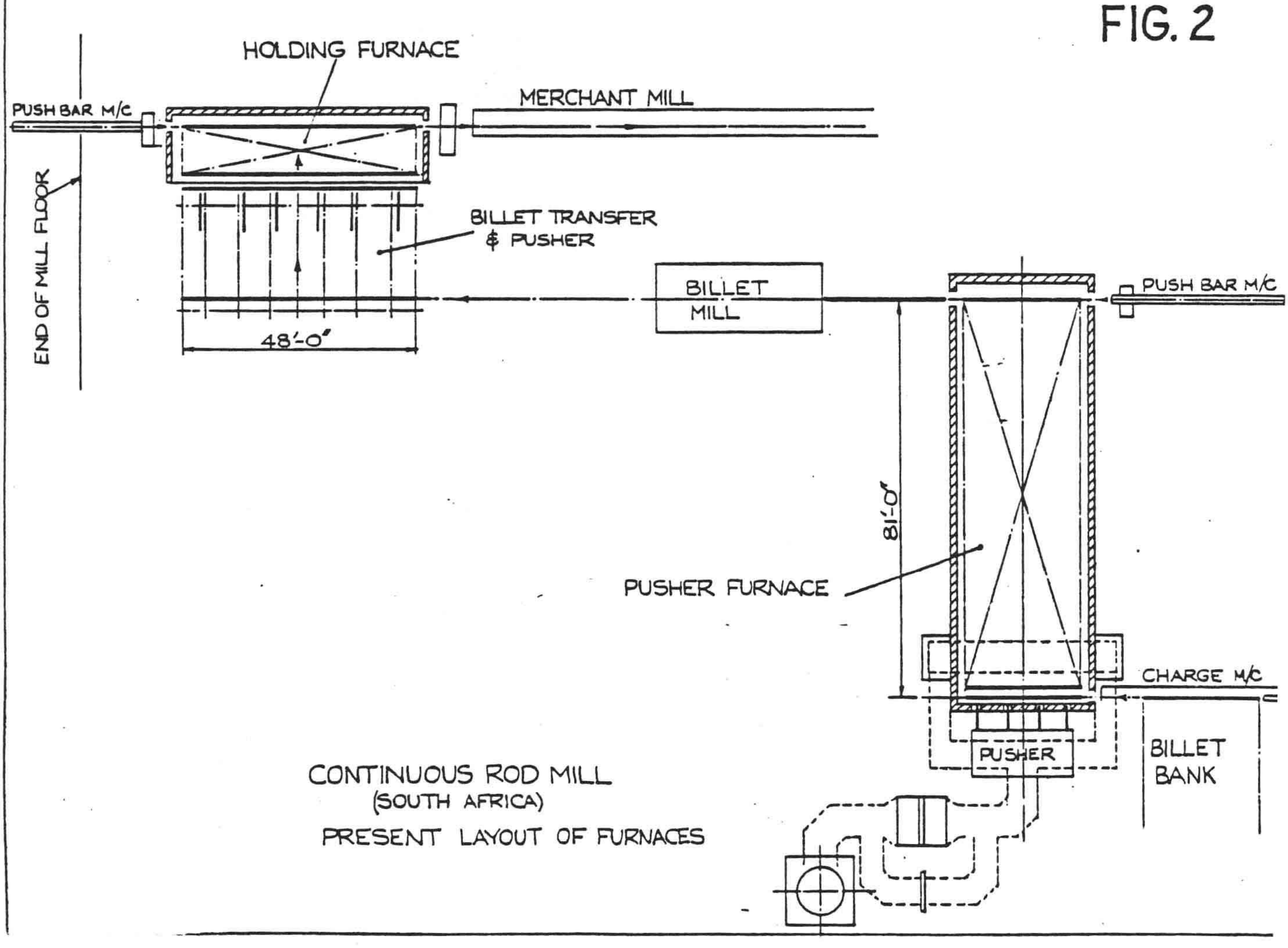
With 81' 0" effective length it appeared to be the longest flat hearth push furnace on record, and concast billets are reputed to be prone to sticking. However, no trouble has been experienced. The efficiency improved significantly and the extra zone added in 1973 was not required to achieve the higher tonnages. Maintenance costs dropped dramatically, and billet heating equality was satisfactory. Fig. 2 shows the layout after there alterations.

FIG. 1



CONTINUOUS ROD MILL
(SOUTH AFRICA)
ORIGINAL LAYOUT OF FURNACES

FIG. 2



CONTINUOUS ROD MILL
(SOUTH AFRICA)
PRESENT LAYOUT OF FURNACES

The reheating furnace has been rebuilt again this year, due to the suspended roof refractories becoming due for replacement, and a changing order situation. Suspended refractory construction can have a long life, but is expensive. Simple ceramic fibre constructions have been developed which have lower cost and are much quicker to install. They can be made into light removable panels, which can give good access to the furnace for repairs. The new roof is therefore ceramic fibre, fixed to removable panels over about 2/3 the furnace area. The heating zone burners have been repositioned in the side walls, 4 burners per side. This permits some variation of heat 'placement', to suit output requirements. Instrumentation, controls and the waste gas system remain unaltered. Two water cooled lintels have been removed, giving a slight increase in efficiency. The changing profiles of the Reheating furnace and the Equalising Furnace are shown in Fig. 3.

The alterations have removed some design features which were wasteful of energy, such as water cooled components, and were maintenance 'hazards'. Costs have gone down, and overall output increased. The walking beam type furnace was chosen originally to ensure good uniformity in the billets, but the installation of the 'equalising' furnace probably made this unnecessary, and the pusher furnace meets the requirements adequately.

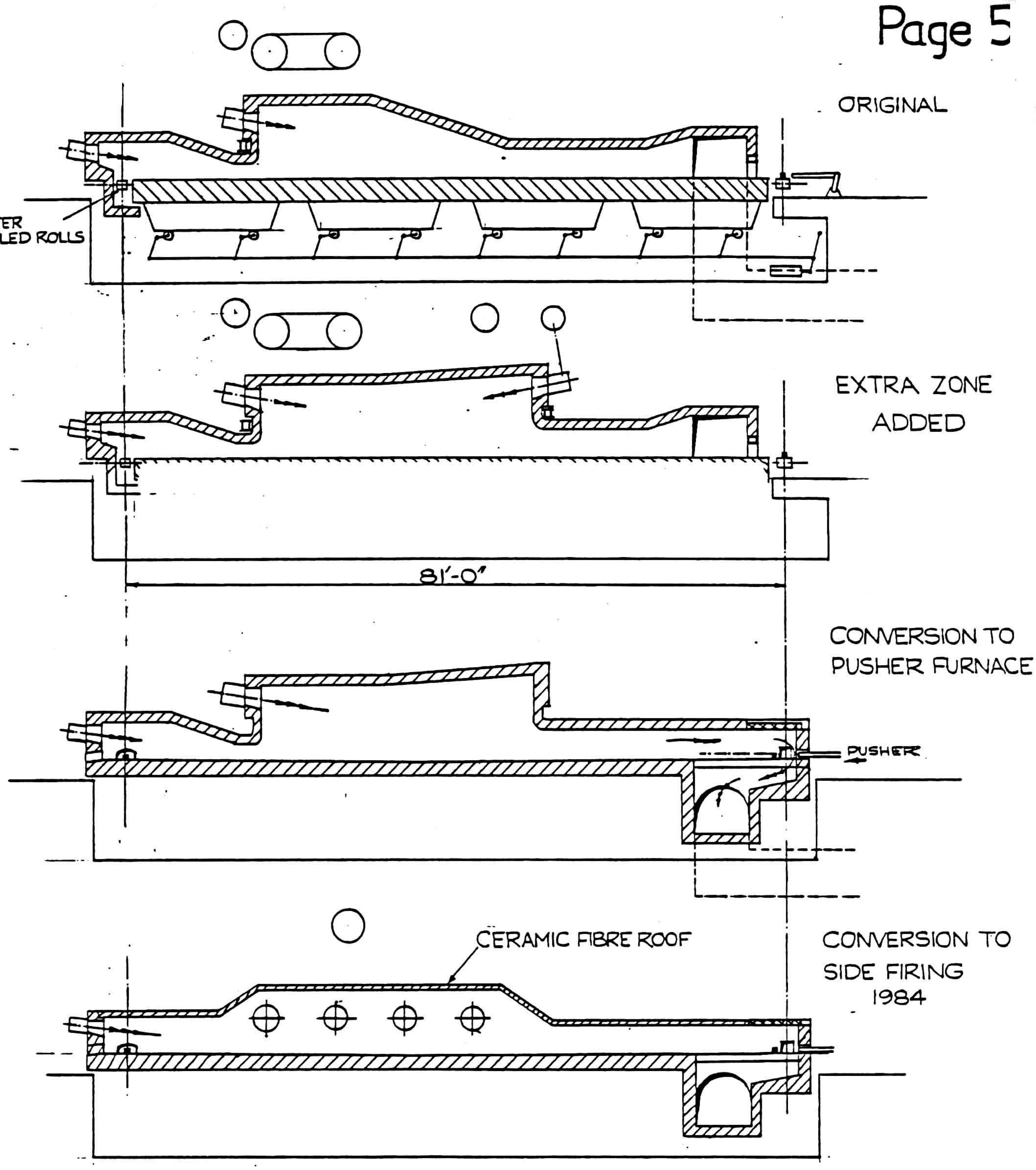
South African low cost coal makes producer gas a popular fuel for large furnaces, and the furnaces have features strange to European eyes now. Although the gas is detarred it is hot and light oils do condense out in the gas mains, and valves get stuck with tar deposits, and do not shut tight. It is customary to use water seals on gas mains to ensure gas tight shut off, and water seals have been fitted to each burner on this installation, to ensure safety when starting the furnace, when burners are lit individually. The plant is at 8000 ft. altitude, which significantly affects chimney draughts, fan performance and flue sizes. Both furnaces have ejector stacks to ensure adequate draught, with fan motors of 15 Kw. and 75 Kw.

Sheffield At this contrasting installation high carbon steel rods and flats are rolled for spring making, from billets 110 square and 2591 long. The fuel is natural gas and outputs are in the range 10-20 tonnes/hour, with quite short runs on a particular size.

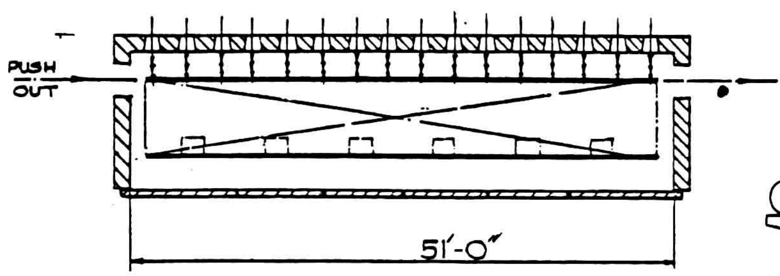
A simple continuous pusher type furnace was originally installed, with burners at the discharge end and supplementary burners in the sides. Excessive scale loss and decarburisation occurred, due primarily to long heating times and holding for periods at temperature, and it was necessary to reduce these. The solution adopted was to have two furnaces, one preheating billets to about 750°C. acting as a reservoir to feed a 'final heat' furnace, heating billets rapidly to 1150°C. - 1200°C. At 750°C. the steel can be held for long periods without damage, and rapid final heating minimises scaling etc.

The existing pusher furnace was shortened to serve as a preheat furnace, and a new small walking beam furnace installed alongside, with a billet handling system between furnaces and mill. This arrangement is shown in Fig. 4, and was dictated by the reality of the site and the need to keep cost to a minimum. Existing equipment such as the push bar was retained. A recuperator had been fitted to the pusher furnace, which was in very good condition; it was altered and used on the new furnace. A large old stack draughted the furnace, and was big enough to draught the new furnace also.

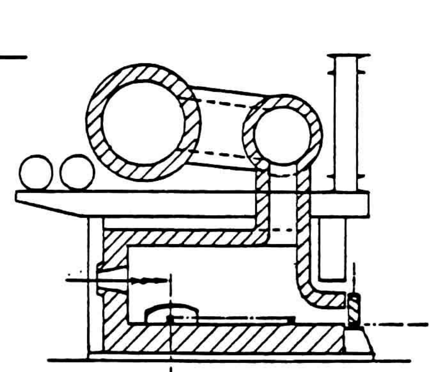
The 'final heat' furnace has a single beam, taking a single row of billets. Billets from the preheater enter via roll tables and water cooled rollers inside the furnace, the beam lifting the billet off the rolls. At the discharge end the billets are deposited on water cooled rolls inside the furnace, and travel to the mill via roll tables.



MILL FURNACE CHANGES



PLAN



HOLDING FURNACE

SECTION THRO' FURNACE

FIG. 3

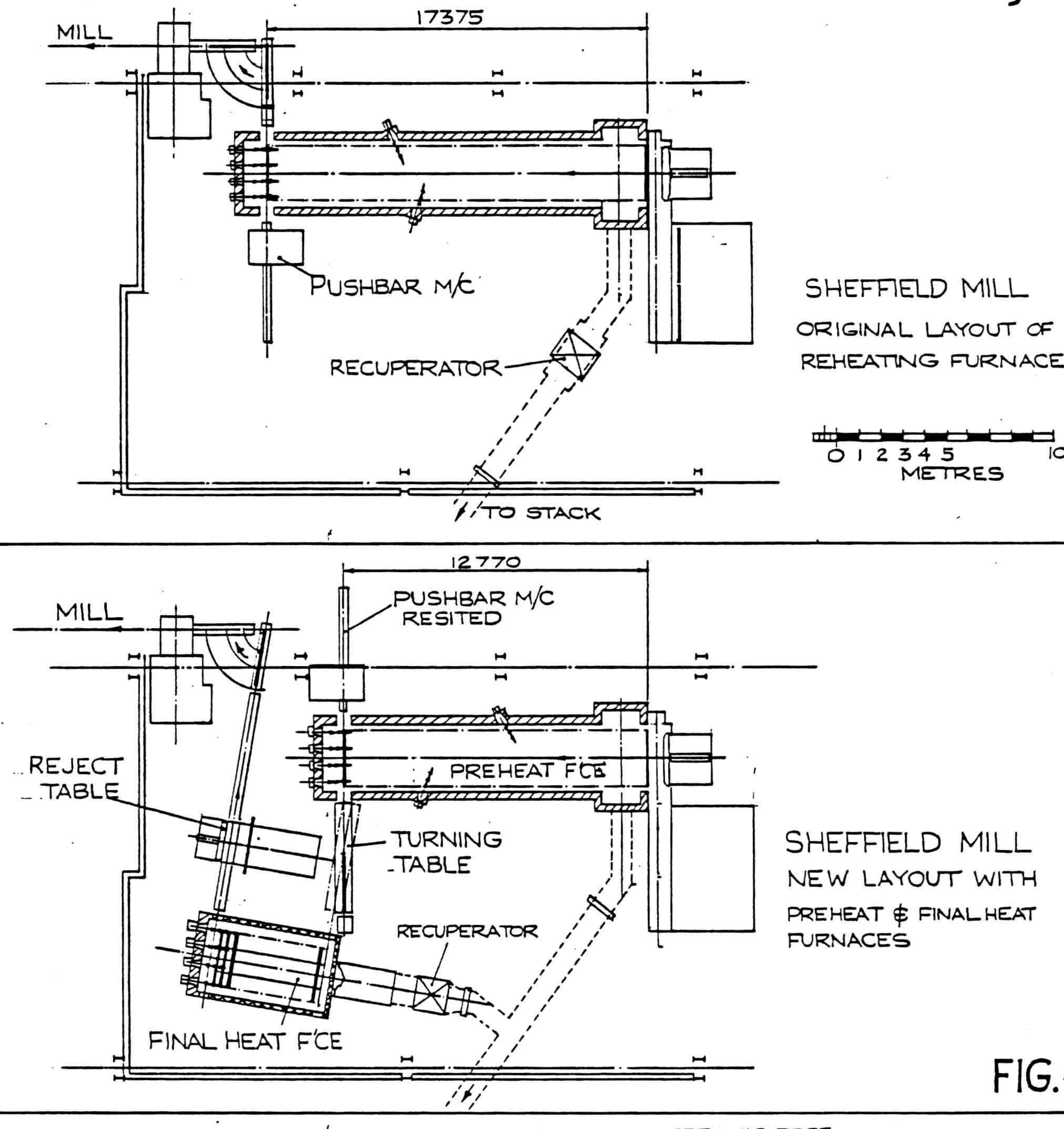

17375
MILL
PUSHBAR M/C
RECUPERATOR
TO STACK
SHEFFIELD MILL
ORIGINAL LAYOUT OF
REHEATING FURNACE
0 1 2 3 4 5 10
METRES
12770
MILL
PUSHBAR M/C
RESITED
REJECT
TABLE
PREHEAT F'CE
TURNING
TABLE
RECUPERATOR
FINAL HEAT F'CE
SHEFFIELD MILL
NEW LAYOUT WITH
PREHEAT & FINAL HEAT
FURNACES

FIG.4

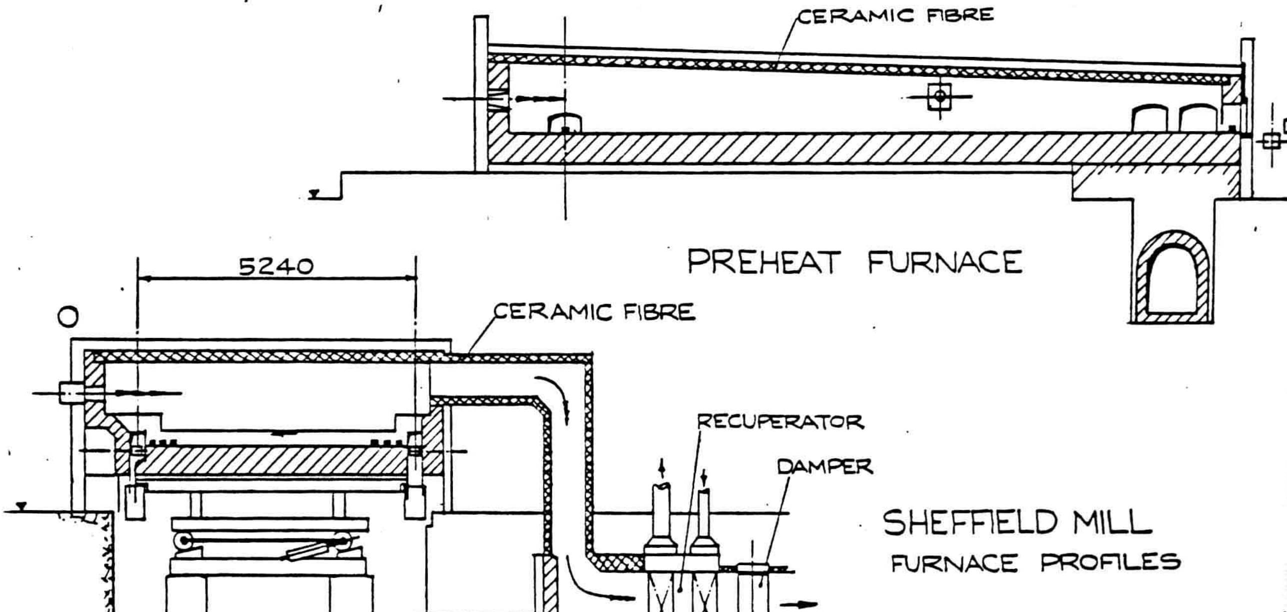

CERAMIC FIBRE
C
PREHEAT FURNACE
5240
O
CERAMIC FIBRE
RECUPERATOR
DAMPER
SHEFFIELD MILL
FURNACE PROFILES
FINAL HEAT FURNACE
0 1 2 3 4
METRES

FIG.5

The furnace is end fired, of simple box shape, with walls and roof lined with ceramic fibre modules, and the beams and hearth edges of mouldable and castable refractory. The waste gas flue is ceramic fibre lined. The burners are controlled as one zone, with air/gas ratio control with air preheat correction. Furnace pressure control is fitted, and recuperator protection is by waste gas dilution to 800^{o}C. with hot air bleed also.

In operation the mill calls billets as required from the 'final heat' furnace. A sequence of beam 'walking', roll and door operation discharges a billet to the mill, leaving a space to be charged. The preheat furnace operator then discharges a billet, which passes to the final heat furnace via a roll table, and is turned through 90^o. The preheat furnace tends to produce billets with a cold bottom face, and turning them presents the cold face towards the burners in the final heat furnace, aiding temperature uniformity.

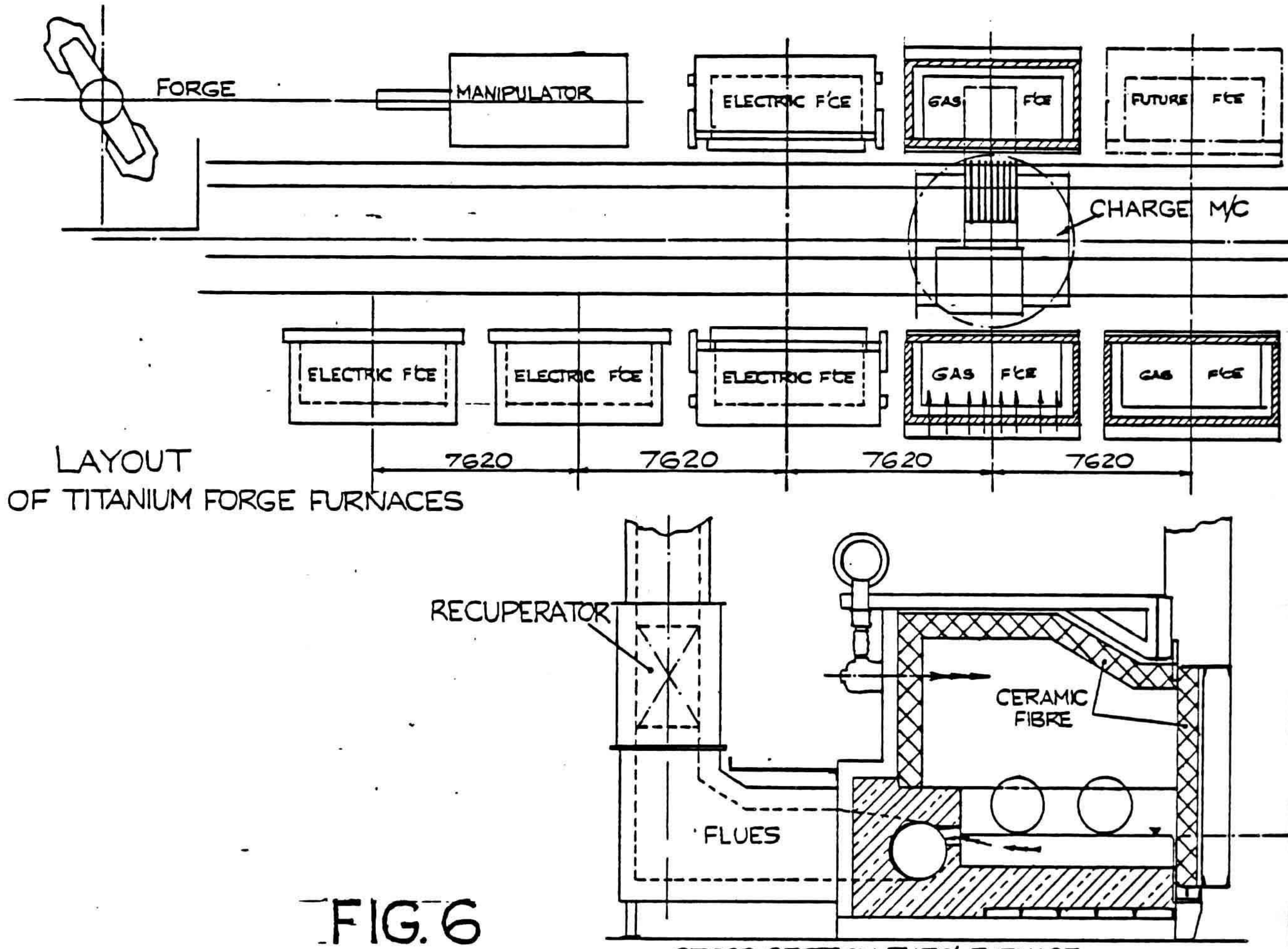
It was necessary to shorten the original furnace in order to fit in the new 'final heat' furnace, and the side burners were moved to alter the furnace temperature profile. At high outputs the heating quality deteriorates, and turning the billets in transit is beneficial.

This installation has been changed from one simple furnace to two furnaces adding features which were discarded on the previous installation discussed. The cost of improved quality is higher fuel consumption and maintenance costs, but rejection of finished material has been virtually eliminated, and scale losses much reduced. The furnace profiles are shown in Fig. 5.

The energy consumption of these furnaces is high, compared to a conventional billet heating furnace. The water cooled components in the final heat furnace are necessary to obtain the operational flexibility required. The high waste gas temperature in this furnace is unavoidable, and expensive recuperators and combustion equipment are required if full recovery of the waste heat is to be obtained. Preheated air at 800^{o}C. is probably obtainable but metal recuperators are then running at the limit of the available materials, and control valves, mains etc. present difficulties also. The cost is also high, with the risk of short life, as there is little lattitude for abuse. This is reality, and it is customary to opt for lower preheats, fuel consumption tending to be secondary to furnace reliability, and hence availability.

Approximate energy balances for these two installations are shown in Fig. 7, for steady running conditions. These figures look quite good, in terms of therms/tonne, but can change dramatically if these 'continuous' furnaces are worked at low outputs, held idle for periods, or shut down between shifts. It is now appreciated that careful operation can produce significant fuel savings and an operational 'strategy' is usually evolved, particularly for the two-furnace installations. Fuel inputs are reduced as soon as mill stoppages etc. occur, and when stock sizes change. With care a two-furnace installation can achieve an overall figure of 22 therms/tonne.

Low thermal storage refractories would not seem to be of much benefit for continuous type reheating furnaces. However, their use is increasing, as in these two installations; helping with the lower utilisation, and giving better insulation, and lower installation costs. Their use is confined to side walls and roof, but these are large areas, giving quicker response to temperature alterations.

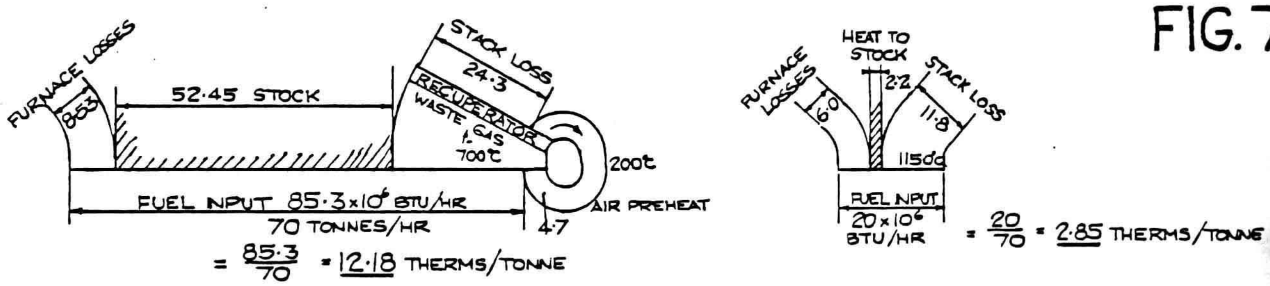


LAYOUT OF TITANIUM FORGE FURNACES

FIG. 6

CROSS SECTION THRO' FURNACE

FIG. 7

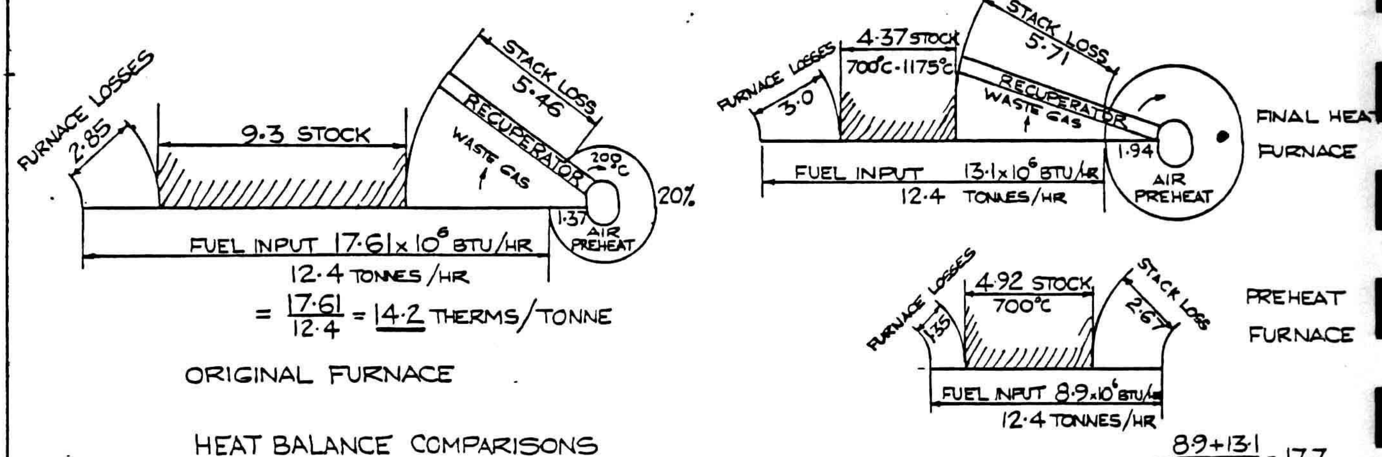


MILL FURNACE

HOLDING FURNACE

OVERALL 15 THERMS/TONNE

HEAT BALANCE- ROD MILL FURNACES - (SOUTH AFRICA)



ORIGINAL FURNACE

HEAT BALANCE COMPARISONS
SHEFFIELD MILL FURNACES

NEW FURNACES

Three Forge Furnaces

Large ingots for forging are usually heated in 'batch' type furnaces, and problems of handling and placing in the furnace can produce awkward furnace shapes.

An installation in Birmingham serves a forge making Titanium forgings from ingots, typically 530 dia. x 2100 Kg. Initially electric batch furnaces were installed, with hearths 5350 wide. x 2300 deep, slotted to accept 'fingers' of a charging machine to handle ingots in and out. There are two temperature levels, 850^{0}C. - 1125^{0}C., the latter causing problems with the metallic electric elements.

The new gas fired furnaces had to have the same hearth size as the electric furnaces, and fit the site. Close temperature uniformity limits were required to conform with customers specifications, much of the work being aerospace components. As the shop environment is controlled, a maximum casing temperature of 75^{0}C. was specified.

The arrangement adopted is shown in Fig. 6 with burners in the back wall. Waste gases are exhausted below hearth level at the back wall, to promote flow under the ingots. A recuperator is fitted, with the air preheat limited to 300^{0}C. to suit the nozzle mix type burners and the operating temperature range.

The furnaces have firebrick hearths, but the side walls, door and roof are lined with ceramic fibre modules. The heat losses are very low, demanding a high 'turndown' range for the burners, particularly on 'soaking' conditions at low temperatures. The control concept is combustion air regulation with gas flow controlled by proportionators. There is a minimum waste gas flow to give acceptable temperature uniformity, and at this combustion air setting, the gas ratio is altered, to give a lower gas input in effect 'excess air' conditions. The 8 burners are controlled in 4 zones because the long narrow hearth can be unequally loaded. Site restrictions as well as the hearth shape dictated placing the burners in the back wall.

The door posed the biggest constructional problem. It is very wide, and the frame depth is restricted. A simple ceramic fibre seal is fitted, with pneumatic clamping gear at each side. The clamp gear guides the door when lifting to ensure that the fibre seal does not drag across the surround castings faces, and suffer mechanical damage. This has proved very successful, and the doors have remained tight with minimal maintenance.

At 850^{0}C. the furnaces are required to be within $\pm$ 10^{0}C. as measured with thermocouples in load blocks on the hearth. 530 dia. ingots with a total weight of 8350 Kg. can be heated to 1125^{0}C. in 5.2 hours, and the maximum load of 13,640 Kg. in 8.5 hours. Fuel consumption is around 23 therms/tonne when heating. Fuel consumption is high, in terms of therms/tonne, if the furnaces are held for long periods on 'soak' conditions. The problem is achieving temperature uniformity with low heat inputs. High velocity burners, with 'pulse' firing, if they could be positioned correctly, or recuperative burners could be alternatives to the existing burners.

In this installation, the restraints were imposed by the site and the ingot handling arrangements, and were more restrictive than usual. There was little choice in positioning the burners for example, because the rear wall is the only accessible area, as the furnaces are very close together.

Conclusions

The furnaces described are relatively small, and operators at this scale tend to have the same order of priorities, namely reliability, low capital cost, performance and fuel consumption. Deficiencies in performance can often be tolerated, but failures mean costly lost production. Fuel may be a small cost component. At 35p/therm the two furnace installation costs £7.7/tonne, less than 2% of the product selling price. Maintenance is a reality to be taken into account also. Staff with a good understanding of combustion principles and controls are frequently lacking, and sophisticated systems may not survive, or perform badly with no better result than a simple system.

Most continuous reheating furnaces are counterflow heat exchangers, and it seems sensible to utilise the self recuperative effect as much as possible, designing for lower heating rates, i.e. longer furnaces. This is simple and relatively cheap. Good basic design should minimise water cooled components and inspection doors, and avoid large charge and discharge openings, which make furnace pressure control difficult. Lower waste gas exit temperatures make heat recovery equipment cheaper and longer lived.

A recent development is to use the waste gases to preheat the stock. This takes two forms; a furnace extension with recirculated waste gases (convection) or a separate unfired chamber, heated by waste gases. In theory this is a good idea, and recuperation can be either abandoned or supplemented. In practice we suspect that the capital cost of the equipment is high, and difficult to justify.

Batch furnaces, and 'hot charged' continuous furnaces pose a different problem. The waste gas temperatures are inevitably high, and the heat recovery problem more severe.

Heat transfer in these furnaces is largely by radiation and ceramic fibre is extensively used, which recent work has shown to have a very low emissivity at high temperatures. If the refractory emissivity could be increased, then lower operating temperatures could be used, and efficiency will be significantly higher. Surface coatings are available which claim to greatly increase emissivity values, and if viable should surely be exploited. This is an area where the theory really would work in practice, and is extremely simple.

We would conclude that advances in refractory linings have been extensively applied to reheating furnaces giving lower installed cost and greater efficiency. Heat recovery however, appears to have fallen behind in practice, despite new developments in burners and recuperation.

There is another 'reality' here, new furnaces are frequently sold in 'package' deals with the mill, and the sellers are concerned to have the lowest price furnace. Here simplicity is favoured. Later, these furnaces are often found wanting by the user and are then altered or replaced.

A new furnace for an established user is usually a different story, and the user contributes a significant design 'input' into the furnace. In the examples given this was certainly the case, and the close co-operation given contributed considerably to a successful job.

MODERN INDUCTION HEATING AND HEAT TREATMENT

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Electricity Council

1.0 Introduction

The use of induction heating for industrial processes began in the United Kingdom in the 1940's and spread quickly as the benefits of this rapid, clean and precisely controllable technique became apparent. Experience gained from early installations evolved heater designs which are now accepted as standard and well proven practice for many applications in metal heating and heat treatment. This paper reviews induction heating plant now available for both established and more recent applications. Special reference is given to developments which are contributing to the more effective use of energy both in terms of energy cost and in terms of other resources which influence total production costs.

2.0 Principle of induction heating

When a metal workpiece is placed in a coil, supplied with alternating current, the two are linked by an alternating magnetic field, so that an induced current heats the metal. The coil itself is water cooled and remains cold (see Figure 1).

The induced current density is greatest at the surface of the workpiece, reducing as the distance in from the surface increases. The depth below the surface in which approximately 90% of the induced heat is developed is termed the penetration depth. The value of the penetration depth depends on the frequency of the alternating current and on the resistivity and magnetic properties of the metal.

Control of heat penetration by frequency selection is clearly a major advantage for surface hardening. Through heating is required for metal working but the penetration depth is normally kept to within a quarter of workpiece diameter to ensure high efficiency. Nevertheless, the generation of heat within the metal itself means that much higher power densities can be achieved than by systems which rely on heat radiation or convection to the surface of the workpiece.

3.0 Power sources

Although work of suitable materials and dimensions can be heated at mains frequency (50Hz), the majority of applications require higher frequencies in the range 150Hz to 500kHz. Generators are therefore necessary to convert mains power to these higher frequencies.

The ranges of frequencies available for induction heating in addition to 50Hz were originally 150 and 450Hz from frequency multipliers; 1-10 kHz produced by rotating equipment (the upper limit being set by mechanical constraints), and the requirement for higher frequencies was met by thermionic valve generators generally operating around 500 kHz (radio frequencies). Nearly all metal working and heat treatment applications above 50 kW were supplied either directly from the mains or by rotating generators while those below 50 kW were mainly powered by radio frequency generators.

3.1 Thyristor generators

Rotary generators have now been rendered obsolescent by the development of solid state generators which began in the late 1970's. These generators, based on thyristor circuitry have several advantages over rotary equipment. They are quieter, smaller in size and their frequencies automatically adjust during the heating cycle to match changing load conditions. But the two most significant benefits are undoubtedly their higher conversion efficiencies and lower capital cost.

Figure 2 compares conversion efficiencies (output power expressed as a percentage of 50Hz input power) for the two types of generator. The solid state equipment not only achieves 95% at full load compared to 85% but is able to maintain this efficiency down to half the full load rating.

In 1974 solid state generators were available at about 70% of the cost of equivalent rotary equipment. While this in itself was a worthwhile reduction, subsequent developments in circuit design and in solid state devices themselves have resulted in further reductions. The result is that the present day cost of a 600 kW, 1kHz unit for instance is less than 60% of the 1974 price in real terms.

About 4 years ago the range of frequencies available from thyristor generators was extended beyond the 10kHz value with the "TQ" generators developed by Radyne Ltd and operating at 25-40kHz. It is claimed that this frequency range is satisfactory for a large part of the work which previously required radio frequency valve generators. Again this advance makes possible a change to equipment of considerably higher efficiency coupled with reduced capital cost.

3.2 Transistorised radio frequency generator

The latest chapter in the story of generator development comes from Cheltenham Induction Heating Ltd (CIH) who are now manufacturing their own design of solid state generator operating in the frequency range 80-200kHz with output ratings from 0.5kW to 12kW (fig 3). The new generator is based on the transistor rather than the thyristor but it is much more than a transistorised conventional radio frequency generator. The tank circuit is incorporated in the workhead, which can be positioned up to 10m from the main cubicle, to which it is connected by conventionally insulated 440V power cable. The tank circuit can be tuned by capacitors to provide adequate kVA to match a wide range of heating loads - both ferrous and non-ferrous.

Conventional valve generators are associated with high cubicle ac and dc voltages of at least 6kV. In the cubicle of the new generator, the highest voltage is the incoming three phase 415V mains supply. This is transformed and rectified to only 200V dc and a transistorised ac voltage controller provides generator power control. The very high conversion efficiency of 90% means that the cooling water requirement is much less than for conventional generators, which are typically 55% efficient. The other fundamental difference is the built-in microprocessor which provides control of the generator and the heating process and which can also be integrated with other associated computer controlled equipment. Parameters controlled include frequency, output power and process time, the latter two by continuous comparison with pre-set values. The microprocessor also provides a 'status condition' on a digital read-out to indicate a series of coded fault conditions. Other information available from the read-out includes voltage, current, frequency, power, timer setting and count down and number of heat cycles.

Applications for which the new generators are in use include heat treatment of small rectangular section steel wire from 1.5mm to 6mm wide. The process involves continuous annealing at a temperature of 720°C and a rate of 40m/min. Another installation heats 0.4mm thick steel strip to cure an adhesive by which a felt backing is attached. At the time of writing CIH have supplied more than twenty of these new generators to industry, all of which have been free from any major service problems.