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a comparison of
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Comparison of operational features and results of the two hot strip mills at Vanderbijlpark Works

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This paper sketches the history of the two hot strip mills at Iscor's Vanderbijlpark Works and explains the reasons for the installation of a reversing rougher in both the 1440 mm and 2050 mm mills and the effect of the economic and market climate on the future development of these mills. The operating and maintenance practices are discussed and comparisons are drawn with respect to the results achieved in the two mills considering manpower energy, capacity, utilization, product quality, and costs.

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The two hot strip mills which are the subject of this paper are located in the Vanderbijlpark Works of the S.A. Iron and Steel Industrial Corporation, Limited. This is a public corporation which was established in 1928 and is commonly referred to as 'Iskor'.

The Vanderbijlpark Works originated in 1942 when a 110in plate mill was established on a greenfield site some 60 km (40 miles) south of Johannesburg, close to the Vaal River for its water and the Reef, or Witwatersrand, for its market. The initial objective and need for the plate mill was the supply of plate for the Allied war effort during World War 2.

That plate mill eventually became a reversing roughing mill-cum-plate mill for the 6-stand 56in hot strip mill which was built in 1950 as part of a fully integrated set-up for the Vanderbijlpark Works with an ingot capacity of about 800 000 t/a and hot and cold finishing facilities for flat products.

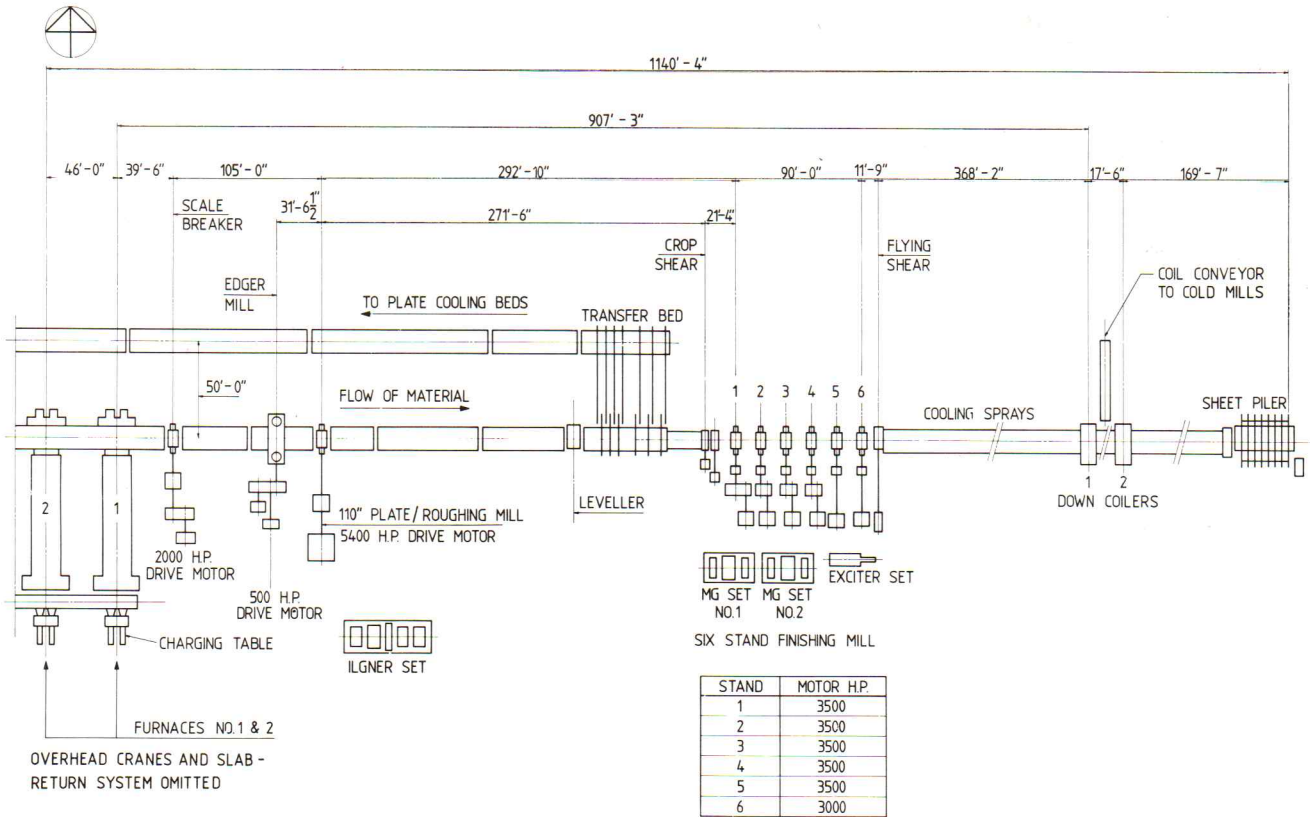
The Vanderbijlpark Works has since experienced two major expansions. The first took place in the mid-sixties when, amongst many things, the hot strip mill was re-vamped and updated and the Works output raised to some 2.5 M ingot ton per annum. The second major extension was begun around 1970 when a complete wide strip facility

was built, including the second hot strip mill with a nominal width of 80in, or 2050 mm.

NARROW HOT STRIP MILL (56in/1420 mm) Original facilities

The mill was originally made up as shown in Fig. 1. Two pusher-type reheat furnaces, with a combined heating capacity of 180 t/h provided the slab reheating facility. They were charged by overhead cranes and discharged on roller tables. The furnace width of 19.5 ft limited slab length to about 18 ft.

Descaling was carried out with two banks of high-pressure water sprays, one at each side of the horizontal mill, together with steam jets for blowing away the loose scale located between the vertical edger and the horizontal mill. The vertical edger was remote from the horizontal mill; it was driven by a single 500 hp d.c. motor, running in tandem with the horizontal rolls. The 4-high horizontal mill was, as mentioned earlier, doubling as a plate mill and as a reversing rougher for the finishing stands. It was powered by a 5400 hp 40–89 rev/min double armature d.c. motor, driving 38in × 110in work rolls via a pinion box; the motor was supplied by three generators on a flywheel MG

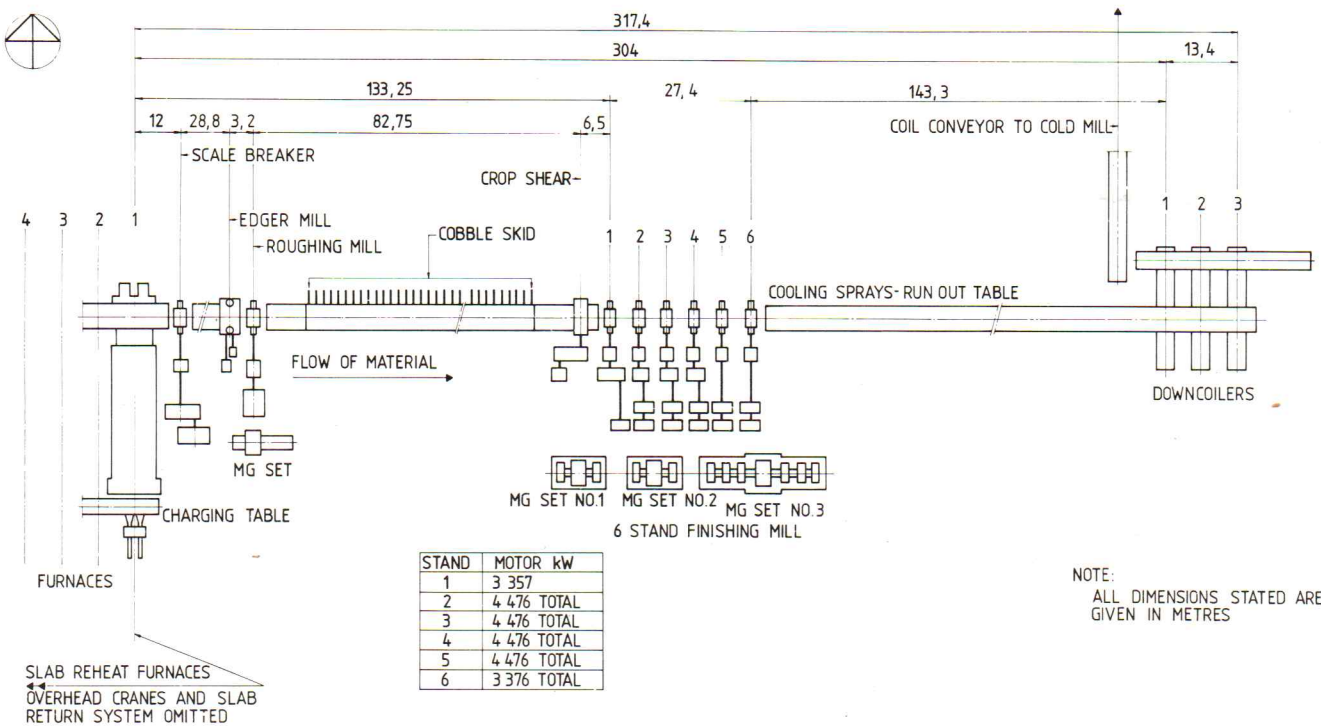


1 Original mill layout, 1950

set. A hot leveller served to flatten plate, while a chequer mill provided for rolled-in footplate patterns.

The six finishing stands were preceded by a rotary crop shear and a tapering spray water descaler. All the motors were powered from a d.c. variable voltage common bus system, generated in two 10000 hp MG sets. The screw-downs were on constant voltage d.c. A flying shear was

close-coupled electrically to stand 6. Strip or cut sheets were delivered via runout tables, equipped with a 5 000 gal/min cooling water spray capacity. Two downcoilers of the driven cluster roll type produced coils with a maximum diameter of 48 in. Cut sheets were passed over the coilers into a passive sheet piler at the end of a further section of runout table.



NOTE:
ALL DIMENSIONS STATED ARE GIVEN IN METRES

2 Modernized mill layout, 1966

Table 1 Data for revamped narrow hot strip mill showing: (a) roughing mill production capacity for 7300 hp drive motor, and (b) 6-stand mill production capacity for 33000 hp drive revamp (t/h)

a		Slab mass, t														
		5.4			7.3			9.2			11.25			6.5		
Slab width, in		20	24	27	27	30.5	34	34	37.5	42	42	46	49.5	42	46	49.5
Slab, p.i.w.		600	500	444	600	531	477	600	544	486	595	544	505	343	313	291
Production rate, t/h		395	451	500	398	459	517	441	460	486	432	441	463	423	450	490

b		Strip thickness, in									
Slab mass, t	Strip width, in	0.062	0.072	0.080	0.090	0.100	0.125	0.1875	0.25	0.375	
5.4	20	223.2	267.3	295.2	342.9	375.3	422.1	471.6	495.9	528.3	
5.4	24	260.1	309.6	339.3	392.4	428.4	483.3	540	566.1	601.2	
5.4	27	287.1	340.2	371.7	426.6	465.3	526.5	587.7	615.6	651.6	
7.3	27	301.5	357.3	396.9	463.5	504	569.7	636.3	669.6	713.7	
7.3	30.5	334	364.5	406.8	485.1	519.3	598.5	696.6	731.7	778.5	
7.3	34	342	358.2	415.8	496.8	532.8	599.4	754.2	791.1	837.9	
9.2	34	332.1	329.4	424.8	513	548.1	615.6	801	843.3	899.1	
9.2	37.5	314.1	310.5	406.8	523.8	548.1	616.5	810	905.4	946.8	
9.2	42	295.2	288	378.9	522.9	548.1	615.6	809.1	981.9	1042.2	
11.25	42	—	—	352.8	531.9	558	629.1	829.8	1017	1108	
11.25	46	—	—	331.2	492.3	522	588.6	804.6	971.1	1181.7	
11.25	49.5	—	—	316.8	457.2	485.1	546.3	747	903.6	1243.8	
6.5	42	333.9	319.5	—	—	—	—	—	—	—	
6.5	46	304.2	297	—	—	—	—	—	—	—	
6.5	49.5	282.6	280.8	—	—	—	—	—	—	—	

An X-ray thickness and an optical width gauge were installed in 1956, but did not at that stage form part of a closed-loop control system of thickness or width. Products on the mill varied between 0.140in and 0.049in in thickness and up to 50in in width, with a coil mass of 5000–13000 lb and a p.i.w. not exceeding 380.

The revamp

With the installation of a 144in plate mill in 1958, the hot strip mill and its roughing mill were committed to full-time strip rolling. The leveller and plate-cooling facilities were removed, the edger mill was re-motored with a twin drive of 2 × 400 hp motors and close speed-coupled with roll diameter and draft compensation to the rougher rolls. A 2000 hp horizontal scale breaker was also installed ahead of the edger, immediately after the furnace delivery table, and is driven by an induction motor.

The facility operated in this configuration for eight years. Market requirements as to tonnage, product range, and quality increased in this period, *inter alia* under the pressure of a rapidly expanding car industry. It became necessary to reconsider the intermediate and ultimate hot mill capacity.

Limiting factors were ingot and slab sizes, as constrained by the metallurgical and slabbing mill capabilities. Further problems arose from crane capacities and the mechanical limitations of the mill housings and their roll drive trains. Overall there was, of course, a ceiling on capital spending, together with the necessity of reducing lost production during revamp work.

Following detailed studies and consultations with the original equipment suppliers, the arrangement as shown in

Fig. 2 was implemented. The main items in this project were the following:

1 Slab mass was to be increased to 600 p.i.w., limited to this figure by furnace capacities within the available space. This was accommodated by widening the existing two furnaces to 22 ft and building two new furnaces. Their heating capacity was set at 117 t/h per furnace.

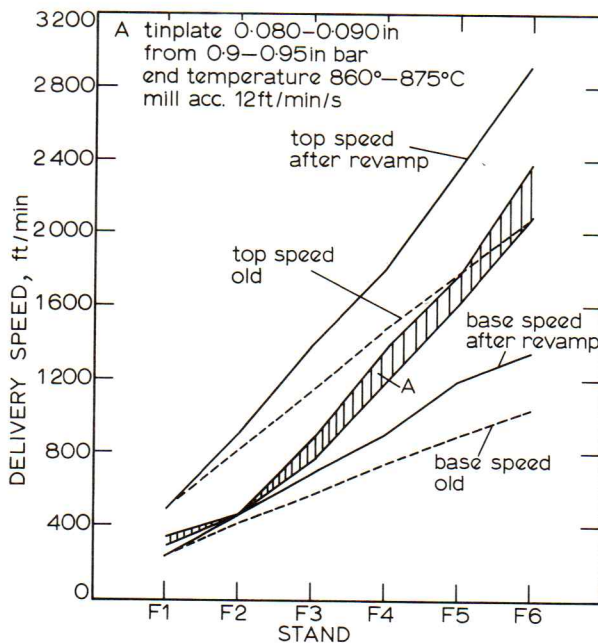
2 A close-coupled edger to the roughing mill was added in order to reduce in-and-out gap times and temperature loss and to reduce the number of slab widths as against ordered strip widths. The old edger was removed and scrapped.

3 The roughing mill housings were brought closer together to save on roll costs. A roll width of 60in was adopted.

4 The roughing mill drive motor was updated to 7300 hp, 54–120 rev/min, through the addition of a fourth generator and a larger motor on its MG set; the flywheel was removed as the electric supply capability had been much reinforced by that time. The production capacity for the several slab sizes was calculated as shown in Table 1a.

5 The six finishing stands were remotored through twinning of existing motors and the addition of new motors, together with a new third MG set of 20000 hp. The control system was changed to individual speed regulators for each stand. The new available rms drive rating, with the modified speed cone as shown in Fig. 3, would roll outputs as shown in Table 1b. This table and the limits on furnace heating provide an insight into the bottlenecks of this range caused by these three components.

6 To obtain improved accuracy and consistency of



	1	2	3	4	5	6
<i>revamp arrangement</i>						
motor, rev/min	175-350	175-350	175-350	175-350	200-400	225-490
gear ratio	20:180	38:87	50:75	58:67	direct	direct
max. roll dia., in	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$
roll type	C steel	C steel	C steel	C iron	C iron	C iron
<i>old arrangement</i>						
motor, rev/min	175-350	175-350	175-350	175-350	175-300	175-350
gear ratio	40:180	35:90	45:83	52:73	direct	direct
max. roll dia., in	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$	22 $\frac{3}{4}$

3 Narrow strip finishing mill speed cone

gauge and yield, a fair amount of automatic control was added. This included a BISRA gaugemeter thickness control, with X-ray gauge override feedback, preset screw positioning operating on variable voltage sources for the existing screw drives, preset sideguide control on the existing constant voltage motors and automatic cropshear cutting. The gaugemeter signals are obtained from bottom backup roll mounted load cells, which required substantial machining of the housings for their accommodation in that location. A further important refinement was the provision of an adjustable mill speed up, to hold strip temperature for the higher p.i.w. slabs.

7 The runout tables were equipped with a more elaborate water-cooling system of the laminar flow type to achieve a better-controlled and consistent coiling temperature. The control is manual, through selector switches and push buttons. The total water volume was increased to 12000 gal/min, supplied from header tanks for the top sprays and pressure regulators for the bottom sprays.

8 Two new mandrel coilers of the four-roll type were installed beyond the existing coilers, together with a new and heavier coil despatch conveyor system. Room for a third coiler was left in the civil engineering provisions; it was actually installed in 1971.

9 Line shaft driven roller tables before and after the roughing mill were replaced with individually driven rolls.

10 Separate sheet shearing facilities were provided to take over the function of the flying shear on the finishing mill, which was removed. Other minor capital items involved improved crop removal and descaling water spray

arrangements. Completely new operators' pulpits were installed at both mills, to allow for better vision and more space for apparatus, desks, and recording instruments.

A particular feature of this project was the fact that the main contract for executive and technical responsibility was entrusted to the electrical equipment manufacturer, with the mechanical builders as subcontractors. The final major shutdown for the revamp was early 1966, after much preparatory work had been accomplished in a number of 3-4 day shutdowns. The job was completed in 27 days, two years from placing the contracts. The cost of the project was approximately R5 M (\$6.6 M), of which 72% was for electrical equipment and engineering.

Operating results

The modernized mill has now been operating for 11 years and it is possible to assess results against the objectives which were set at the time. We have since switched to the ISO metric system for dimensions and the rest of this paper is in this system.

The following figures are representative for 1977:

1 Average monthly throughput: 102 500 t; Maximum monthly throughput: 159 967 t (June 1973)

2 Average yield: 96.3%

3 Average thickness of strip: 2.89 mm (by mass); minimum: 1.6 mm; maximum: 10 mm

4 Nett average rolling rate: 279 t/h or 32.78 slabs/h for an average slab mass of 8.5 t; maximum rolling rate for 8 h shift: 3 112 t (April 1971)

5 Strip width distribution, % (by mass): below 735 mm 4.8; 735–835 mm 11.5; 836–960 mm 29.2; 961–1035 mm 15.7; 1036–1235 mm 21.7; over 1235 mm 17.1

6 Thickness accuracy: + or – 0.05 mm on all gauges, better on thinner gauges

7 Average monthly manned time: 627 h

8 Delays expressed as percentage of manned time: 44.33%

(a) operating delays: 16%, of which work roll changes took 8.12%

(b) services delay: 6.18%, of which backup roll service took 3.59%

(c) maintenance delays: 19.15%, of which finishing stand mechanical breakdowns took 6.52%

9 Material reclassified as a result of quality defects or operational problems: 3.01%, of which temperature problems accounted for 29%, stoppages/trip-out for 21.5%, and cobbles for 9.6%

10 The above output data were obtained with an available total strength of 126 men as direct operating staff, together with 98 men in supporting functions; this actual strength to be assessed against an approved book strength of 145 men for the operating staff for the three shift operating of this mill complex; book strength for maintenance, shift, and day duty is 119 men, as against an average of 96 men available

11 As regards the slab reheating furnaces, the following are approximate figures, only three furnaces being in use at a time:

(a) heat consumption: 2.9 GJ/t

(b) furnace time for slabs: 2.5 h average

(c) gas mixture: coke-oven gas and blast-furnace gas in a volume ratio of 1:0.88; average heat value 0.011 GJ/m³

(d) Heating control via separate top and bottom heating and soaking zones, at 1280°C in the first and 1290°C in the last, except for medium-carbon steel when the entire furnace is operated at 1150°C

(e) Oxygen excess 2.0–3.0% for the heating zones and 3.5–4.0% for the soaking zone

12 Roll practice: All backup rolls are flat. The roughing mill rolls are 0.13 mm concave (radius); the finishing stand rolls are 0.05–0.025 mm concave for the first three stands, while stands 4 and 6 have flat rolls and stand 5 has 0.025 mm top crown and a flat bottom roll.

13 Strip lubrication: Experimenting with lubricant injection into the cooling water headers on Stands 1, 2, and 3 has yielded significant and promising results as regards increasing roll life and lower rolling energy consumption. However, technical problems have cropped up, relative to the equipment used. We are presently awaiting further recommendations from the suppliers of the lubricants.

Problem areas

The above figures tell their own story as to problem areas and possible solutions.

While exploitation of the mill has been good and the yield acceptable, the availability has been less so. The main problem here is the number of roll changes and the difficulties around the backup roll bearings which are still of the metallized type. Also, with the need to upgrade the strip temperature pattern towards the last few stands, because of customer quality requirements, the mechanics of these

drives are increasingly in trouble and will need major capital replacement before long.

The strip lubrication experiments point towards improved roll life and reduced roll changing, if the associated technical problem can be resolved.

The rolling tempo and output rate is also increasingly jeopardized by a deteriorating performance of the reheating furnaces. Their foundations are weakening and their roof structures require substantial rebuilding; the instrumentation also needs updating in the light of our experience with the furnaces of our new wide strip mill. Furnace charging has always been a bottleneck. There is insufficient storage capacity on the charging platforms, especially while charging narrow slabs; operation of the depiling cranes becomes very cramped and slab identification uncertain or difficult. With market expectations for a rising tinplate output, this problem will become much more pronounced and will require a drastic furnace and charging provision rebuild.

The gauge control system has been satisfactory, but has suffered increasingly from problems with the load cells underneath the bottom backup roll chocks; this location is inherently difficult for access and at the same time exposed to ingress of water. We have not yet been able to get the better of this difficulty and the gauge control suffers from non-availability of some of the signals. The burden of this control is then shifted to extra soaking time in the furnace to reduce temperature variations within the body of the slab, again affecting output rate.

The runout table cooling system has, likewise, not come up to expectations. Its greatest problem is the lack of repeatability and consistency owing to indifferent operation of the bottom flow regulating valves and the fact that operation is manual. Improvement will need to be sought in automation and adaptive control computerization, together with a rethinking of the actual water delivery system.

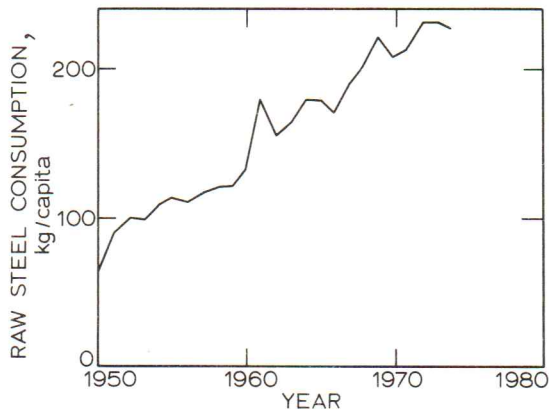
As regards the vertical edger, there appears little that can be done with the existing set-up. However, with a computer-controlled slabbing mill this problem can be reduced to being acceptable, and this is being implemented, but it puts the burden of width control in a different Works department.

A more serious problem is the staffing situation. Being a manually controlled mill, and an old one at that, its operational efficiency is directly responsive to number and quality of operating and maintenance personnel. With the emphasis on modern and automated equipment elsewhere in the Works, turnover and poor induction of suitable personnel are increasingly affecting availability and downtime for maintenance or repairs. This, too, may require significant rethinking and capital outlay in the light of our experience with the wide strip mill, so that the narrow mill may obtain some of the glamour and sophistication which workers now expect.

ECONOMIC AND OUTPUT CONSIDERATIONS

South Africa's economy has been expanding at a steady rate since the end of World War 2. From a Gross Domestic Product¹ of R2 549 M in 1950, it had grown to R4 963 M in 1960 and R7 480 M in 1970 and stood at R15 440 M in 1975, expressed in 1970 prices. Likewise, per capita steel consumption has followed, as shown in Fig. 4, increasing nearly fourfold over the last 25 years.²

This expansion was caused by the vigorous development of the industrial sector. Initially, this centred largely on mining, but increasingly veered towards import substitu-



4 Per capita steel consumption in South Africa, 1950-1974 (from Ref. 2)

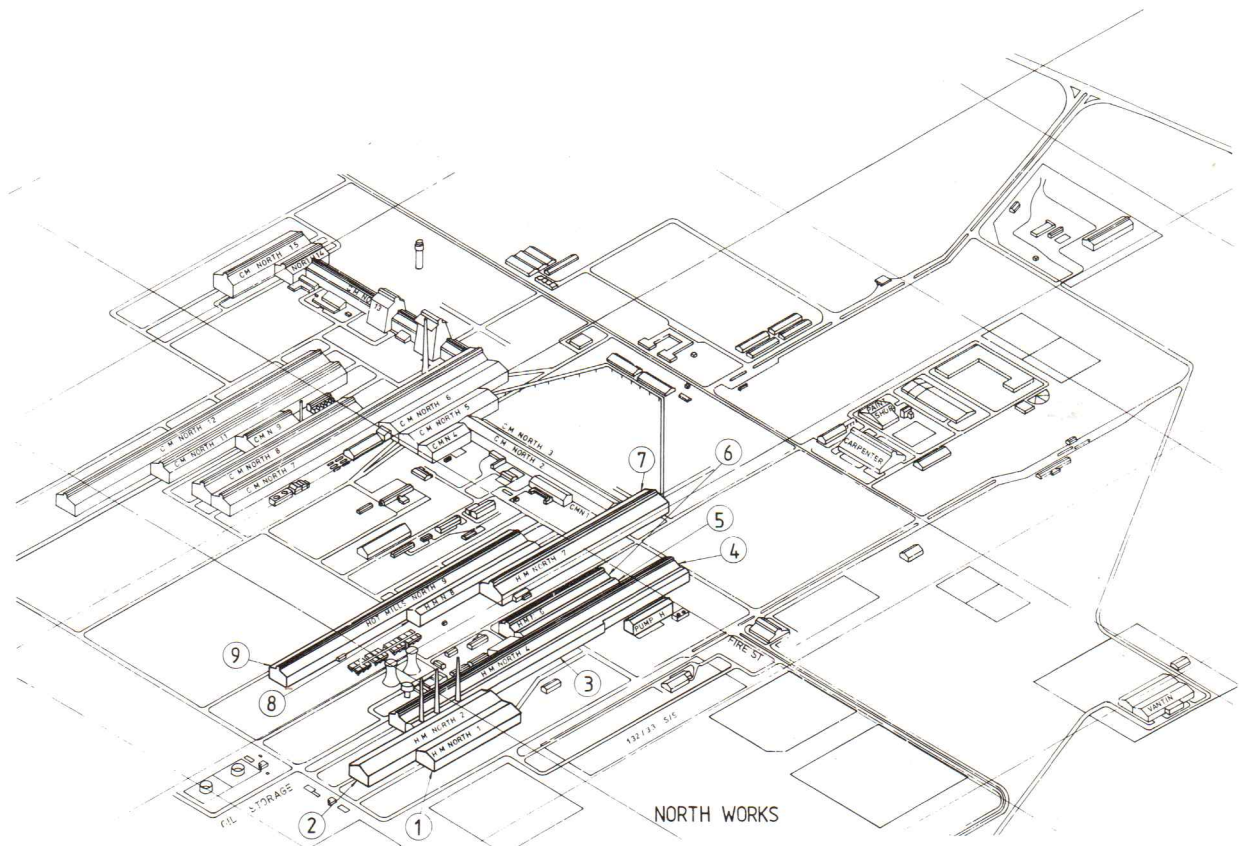
tion, infrastructural elements of transport, water conservation and energy, and production of consumer products as South Africa's internal market developed purchasing power and sophistication.

With this expansion of steel consumption, Iscor's production capacity, together with those of other steel producers in South Africa, was continuously outpaced and required substantial supplementation in the form of primary steel imports.

During the late sixties, therefore, major output expansions were projected initially to further develop the Vanderbijlpark Works and also to prepare for the establishment of a third works, at Newcastle in the Natal Province.

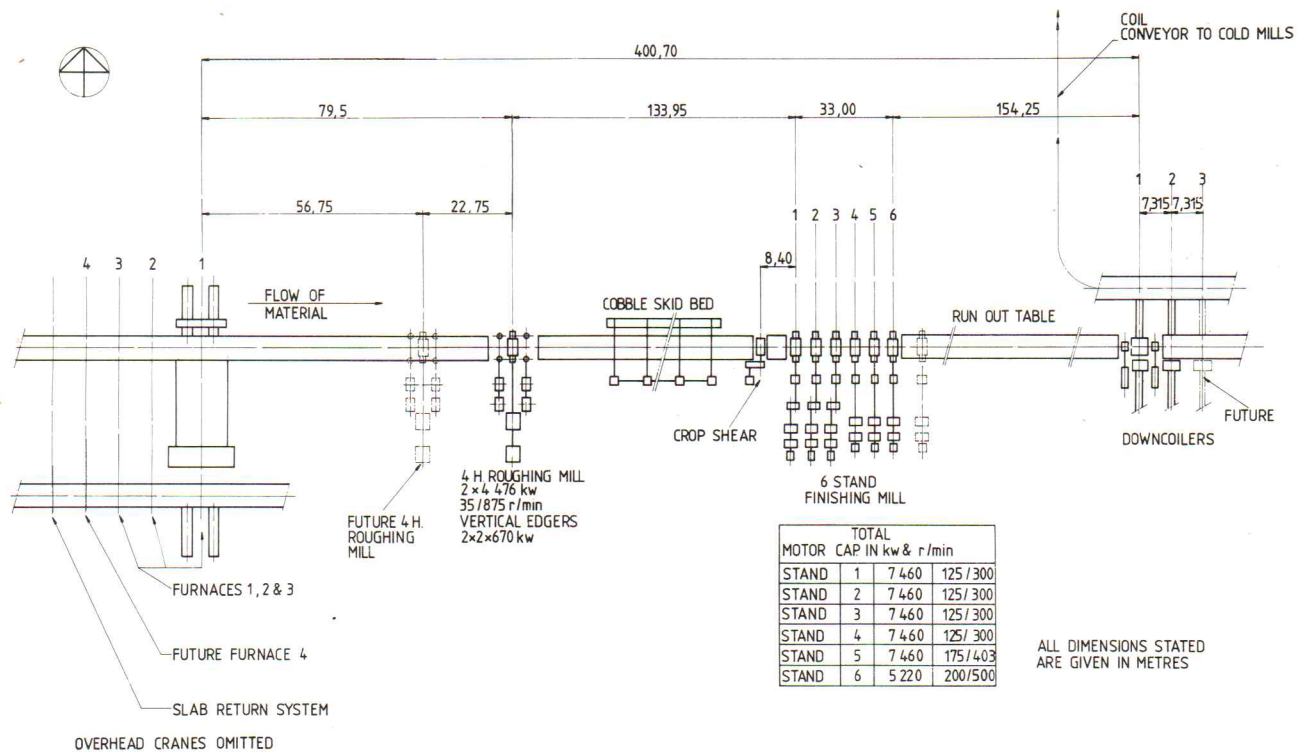
The most critical technoeconomic decision hinged, of course, on the vexed question of strip width versus tonnage as the basis for additional flat product output capacity. Market trends elsewhere suggested that 60-75in widths were beginning to play a significant role in large-diameter pipemaking and also in the automobile and container industry. Another important consideration was that the establishment of a wide strip facility in Southern Africa would, for a considerable time, be a one-off type of exercise considering its capital cost and output capability. Export of temporary excess capacity would, therefore, require to be an intermediate carryover. It has been Iscor's experience that new product ranges stimulate their own demand in the current state of the South African economic system. At the same time it was anticipated that individual orders for steel products would remain relatively small and would be very diversified as to quality and dimensional parameters. It was, therefore, imperative that process sophistication and control should be able to accommodate such market demands in a profitable manner without undue stress on yield and plant availability.

It was decided to establish a complete wide strip facility, nominally for 80 in or 2050 mm. This included a hot strip mill, pickling, tandem cold mill, galvanizing, and shearing facilities. This complex would initially be—and presently



1 and 2, slab yards; 3, motor room; 4, mill bay; 5 and 6, roll grinding and roll storage; 7, 8, and 9, finishing bays; total area of hot mill buildings: approx. 11.25 ha; total area shown: approx. 355 ha

5 The new wide strip facilities



6 The new hot strip mill showing major items and distances

is—supplied from existing metallurgical capacity, boosted by additional blast furnace and BOF plant expansions to a total output of approximately 4 M ingot t/a.

Eventually the wide strip mill complex will require its own separate metallurgical facilities to allow full exploitation of its ultimate capacity.

THE WIDE HOT STRIP MILL (2050 mm/80in)

The wide strip facilities have been built on what was virtually a greenfield site to the north of the existing Works. Figure 5 shows an isometric picture of this new establishment.

The hot strip mill itself is arranged as shown in Fig. 6 which details the major items and their distance relationships.

The project was initiated in August 1969, the contracts placed in January 1971, and the first bar rolled at the end of May 1974. Total cost of the hot strip mill was R80.5M (\$101 M), of which about 75% was for the mechanical, electrical, and electronic equipment. A feature worth mentioning, perhaps, was the fact that this project was built through the successful and harmonious cooperation on site of many nationalities: the Japanese and Americans as equipment suppliers and Spanish as construction workers, together with the several groups of South Africans; a total of 1 600 workers were at one time engaged in this rather large project.

Description of facilities

Slab yards

The end feeding arrangement of the narrow hot mill had proved to be a bottleneck, as mentioned earlier. Hence, in the wide strip mill complex slab charging is effected via two yards which run parallel to the mill bay. One yard receives and stores incoming slabs and the other yard schedules and

charges. The slabs are located and checked under the charging cranes in strict sequence. Each slab has a painted-on number to enable the furnace pusher operator to identify it and to charge it as directed by the computer. This system has proved successful and has eliminated charging delays.

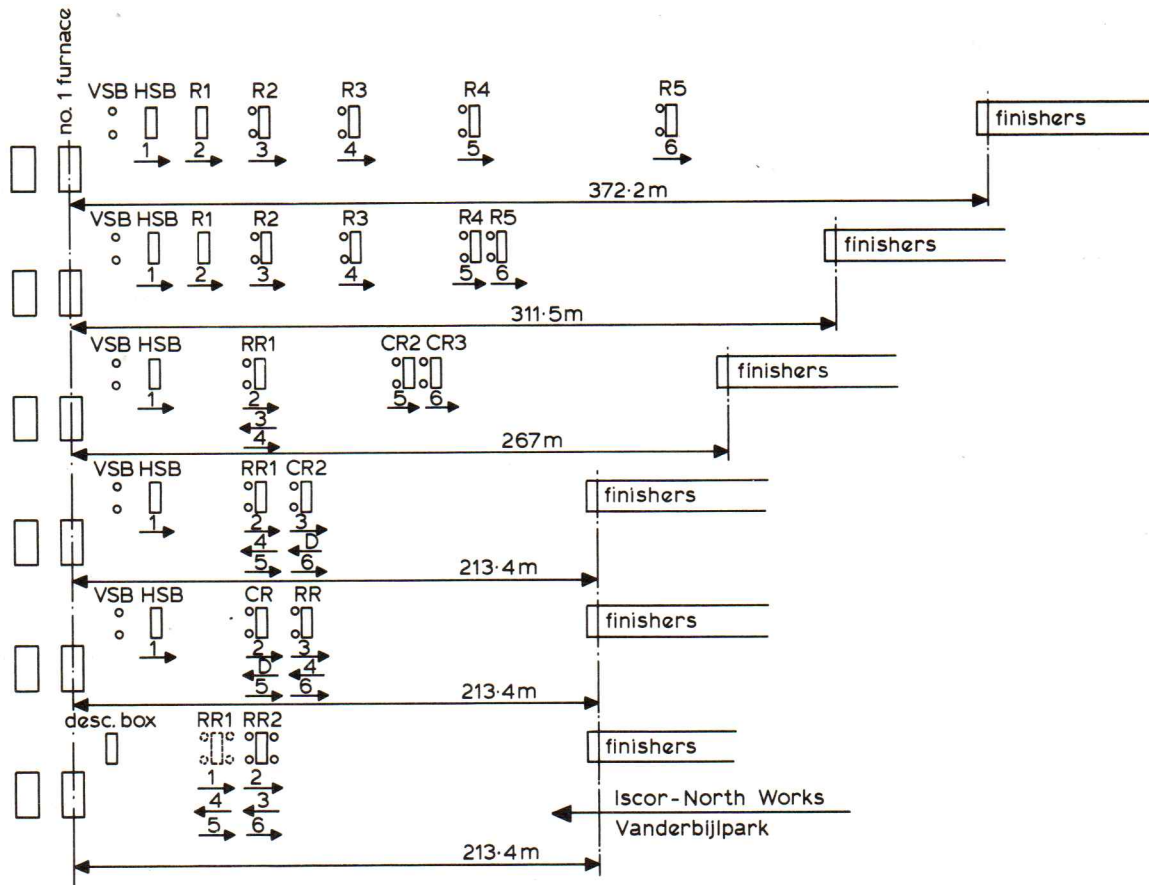
Reheat furnaces

While room was provided for the ultimate of four furnaces, only two were built together with the rest of the complex as a first stage. The furnace capacity was set at 228 t/h each for full floor coverage and constant slab thickness. A third furnace has since been commissioned. The furnaces have a length of 32 m and are subdivided into preheating, heating, and soaking zones.

With walking-beam furnaces being considered too expensive as regards capital costs and fuel consumption rates, we opted to keep to pusher furnaces, as for the narrow mill. However, the skids and discharge arrangements are different. The discharge is by means of extractor beams, as opposed to a drop-out ramp, while cobalt steel runners instead of carbon steel are used on the water-cooled skids. Likewise, a fusion-cast alumina refractory soaking zone floor has been a great improvement as compared with the original rammed alumina of the narrow mill furnace floors. The life obtained is 850 000 t per furnace for an average hearth coverage of 87%.

The six cobalt steel skids and their rectangular-shaped water-cooled supports allow a robust construction and result in very little loss of insulation, with consequent reduced heat losses, as compared with the conventional circular skid shapes. Skid marks are also much less prevalent.

The discharge arrangement on these new furnaces has given some refractory problems as the extractor slots tended to crumble away. By eliminating two of the slots,



7 Arrangement of roughing mill train

this matter has improved and overall operation is now satisfactory.

Since the additional metallurgical facilities were phased to be rather later than the wide mill complex, coke-oven and blast-furnace gas shortages were foreseen and provision was made to fire the heating zones with fuel oil as an alternative at short notice. This has proved a valuable option under the present circumstances.

Descaling equipment

As discussed earlier, the narrow mill has a horizontal scalebreaker mill, together with high-pressure descaling water jets. The wide mill has only water spray descaling facilities. Although this does not have the advantage of a 'pass' of a scalebreaker mill, the capital cost of such a mill was not considered worthwhile against the flexibility which was purchased with the reversing rougher philosophy which will be discussed later.

Table 2 Data for wide hot strip mill showing: (a) roughing mill production capacity for low-carbon steels for 9000 kW drive motor and (b) 6-stand mill production capacity for 42520kW drives (t/h)

a	Slab width, mm											
	800	1000	1200	1400	1600	1800						
Slab, p.i.w.	530	1100	530	1100	530	1100	530	1100	530	1100	530	1100
Production, t/h	375	450	445	520	420	590	470	665	520	685	495	700
No of passes	5	7	5	7	7	7	7	7	7	7	9	9
b	Strip gauge, mm											
	600 p.i.w.				900 p.i.w.				1100 p.i.w.			
Strip width, mm	1.5	2.0	2.5	3.1	1.5	2.0	2.5	3.1	1.5	2.0	2.5	3.1
750	309	393	435	456	352	446	491	532	371	473	523	571
1000	412	524	580	608	469	594	655	709	495	631	698	761
1250	515	655	725	760	586	743	819	886	618	789	872	952
1500	—	786	870	913	—	892	983	1064	—	946	1042	1142
1800	—	—	1015	1065	—	—	1045	1241	—	—	1010	1173

a Assumed gap time, 13 s; slab thickness, 235 mm; Crossover bar, 28 mm; Slab 25 mm wider than strip, max. draught, 50 mm/pass

The main descaling box is located immediately beyond the furnace tables and delivers 12 500 l/min at a pressure of 15 500 kPa. The reversing rougher has headers of 5 600 l/min each on both sides, while a further 15 000 l/min can be selectively discharged at several places in front of and behind stands 1 and 2 of the finishing train, for temperature and scale-pattern control. These rather massive flows and pressure have proved entirely satisfactory.

Roughing mill and edgers

Where the narrow mill, with its (underpowered) edger obtains its slabs from a computer-controlled slab mill, the wide mill was designed to roll its products from slabs which come from our continuous-casting facility. This supplies a much more restricted range of widths in order to optimize its availability. For that reason, substantial edging mill capacity was indicated at the outset and the wide mill complex has been equipped with two close-coupled edgers, powered to take 150 cm² (23.25 in²) reductions. This enables us to accept slab width steps of up to 5 cm (2 in), without loss of width control. Tests have since proved that this arrangement can, in fact, accommodate 15 cm (6 in) width reductions from slab to strip. This does, however, lower production tempo significantly. The twin-edger set-up has also resulted in a much improved 'mill edge' for the finished product.

The selection and arrangement of the ultimate roughing mill train has been a departure from the traditional approaches. These vary from the more-or-less classical constant-speed 5 or 6 roughing mill train, to various combinations of constant-speed stands and a reversing stand. After a study of the immediate and ultimate output requirements of the wide strip complex, we opted for an (ultimate) arrangement of two identical reversing roughing mills, each with two close-coupled edgers. These will be spaced so that the 5th and subsequent passes only will require the bar to be in both mills together.

The main advantages of this arrangement are detailed below.

1 There is an immediate capital saving in table length and associated mill bay and motor room building (see Fig. 7). The capital saving amounted to about 15% in the original outlay, with a further capitalized 7% resulting from the delay of the installation of the second reversing unit for 12 years.

2 It is a very flexible set-up as regards product range and a very close control of head-to-tail temperature.

3 In the event of an eventual stoppage or defect on one of the two roughing mills, about 70% of the product, tonnage-wise, can still be rolled without limitations on dimensional parameters.

4 Since no 'dummy' passes will be required, the output tempo can be increased.

However, these advantages are counterweighted to a certain extent as shown below.

5 There is the disadvantage of increased complexity of sophisticated computer-controlled reversing roughers and their exposure to technical problems and defects. This is, of course, particularly pertinent for the present situation in which only one rougher/edger combination is available.

6 The future capital cost of the second rougher is likely to be a disadvantage as a result of the ongoing inflation rate for equipment of this nature, in the face of steel prices which

are increasingly subject to competition of substitute materials and price restraints.

The selection of the power and speed range of the twin main drive motors was made in consideration of the work-roll diameter (1 120–1 010 mm) to give optimum drafting to the limit of safe bite angle at full width of 1 900 mm. A speed range of 2.5:1, with a base speed of 35 rev/min, gives considerable scope for computer control of temperature and heat conservation. Table 2a illustrates the calculated outputs for this section of the complex.

Finishing train

The six finishing stands have been powered to allow slab sizes up to 37.5 t and 1 100 p.i.w. to be rolled into products from 1 900 mm wide × 13.7 mm thick for high-tensile steels, to 1 200 mm wide × 1.5 mm for low-carbon steel. A crop shear of the retractable cartridge type with double blades (curved front blade) has a capacity of 44.5 mm × 1 900 mm at 900°C.

The tension loopers are electrically powered. Roll bending equipment is provided on stands 4, 5, and 6. It is manually operated from the mill pulpit. Gauge control is by the BISRA method, with the roll separating forces measured by load cells between screwdowns and roll chocks. Stand 6 has provision for the eventual installation of hydraulic roll gap adjustment equipment. Civil engineering is complete for a stand 7 extension to this mill, when market requirements dictate expansion to ultimate plant capacity.

Strip lubrication equipment was installed originally, but has been removed pending further results from the experiments with this technique on the narrow mill. The width and thickness gauges are located immediately beyond stand 6.

A powerful fume exhaust system on stands 4, 5, and 6 has proved a worthwhile expenditure. Roll changing on this mill is performed by a rack and pinion pusher/puller arrangement, with provision for the installation of turntables in the future.

As regards the main drive motors and associated gear drives, the speed cone of Fig. 8 gives these relationships. Stands 1 to 4 have identical motors to reduce spare armature requirements. Table 2b sets out the output capabilities as against width, thickness, and p.i.w. parameters.

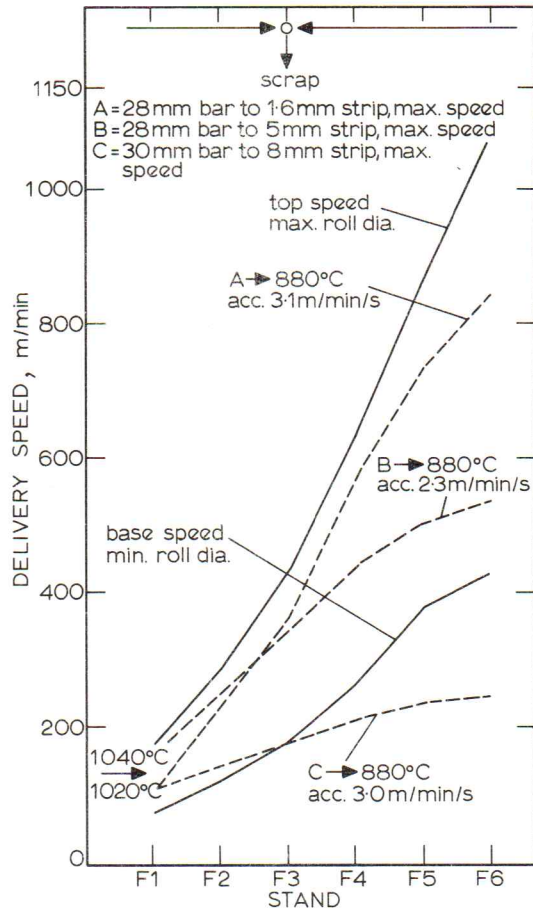
The entire complex is thyristor powered for all main and auxiliary variable speed drives. Dynamic power factor compensation and harmonic filters to comply with Utility requirements have been provided; stability problems in this regard were avoided through a comprehensive system analysis and the definition of appropriate circuit parameters.

Runout tables

The runout tables have an extensive laminar flow strip cooling system. This consists of 102 top header units and 104 bottom header units; each header unit carries 80 nozzles. The maximum flow which can be delivered through this system is 425 000 l/min from constant pressure header tanks into 17 top and 17 bottom zones, individually controlled by air pilot valves. The control of the zones is by the computer, from a statistical model, updated from temperature scans at 17.8 m strip length intervals.

Downcoilers

Mandrel type coilers with three unit cluster rolls were chosen for their simplicity and robustness; two of these



	F1	F2	F3	F4	F5	F6
rev/min	125-300	125-300	125-300	125-300	175-403	200-500
gear	3-718:1	2-231:1	1-488:1	direct	direct	direct
roll dia., mm	765-707	765-689	765-670	765-682	765-696	765-710

8 Wide strip finishing mill speed cone

have been completely installed. The coilers are retractable so as to allow maintenance to be carried out while the plant is in operation; this has proved to be a valuable decision. A feature of specific interest is the very long entry side guides (26 m), ahead of coiler No. 1. They are provided with replaceable 15 m long parallel wearing plates and, together with the three unit cluster rolls, allow good tight coils to be produced.

The tension control of the mandrel drives contains both tension and bending torque references, calculated and set by the computer for each product.

Process control computer system

During the initial planning it was decided that the mill was to be computer controlled to meet the present and future strip dimensional and metallurgical tolerances for subsequent process and market requirements and to accommodate the small order sizes with an acceptable yield.

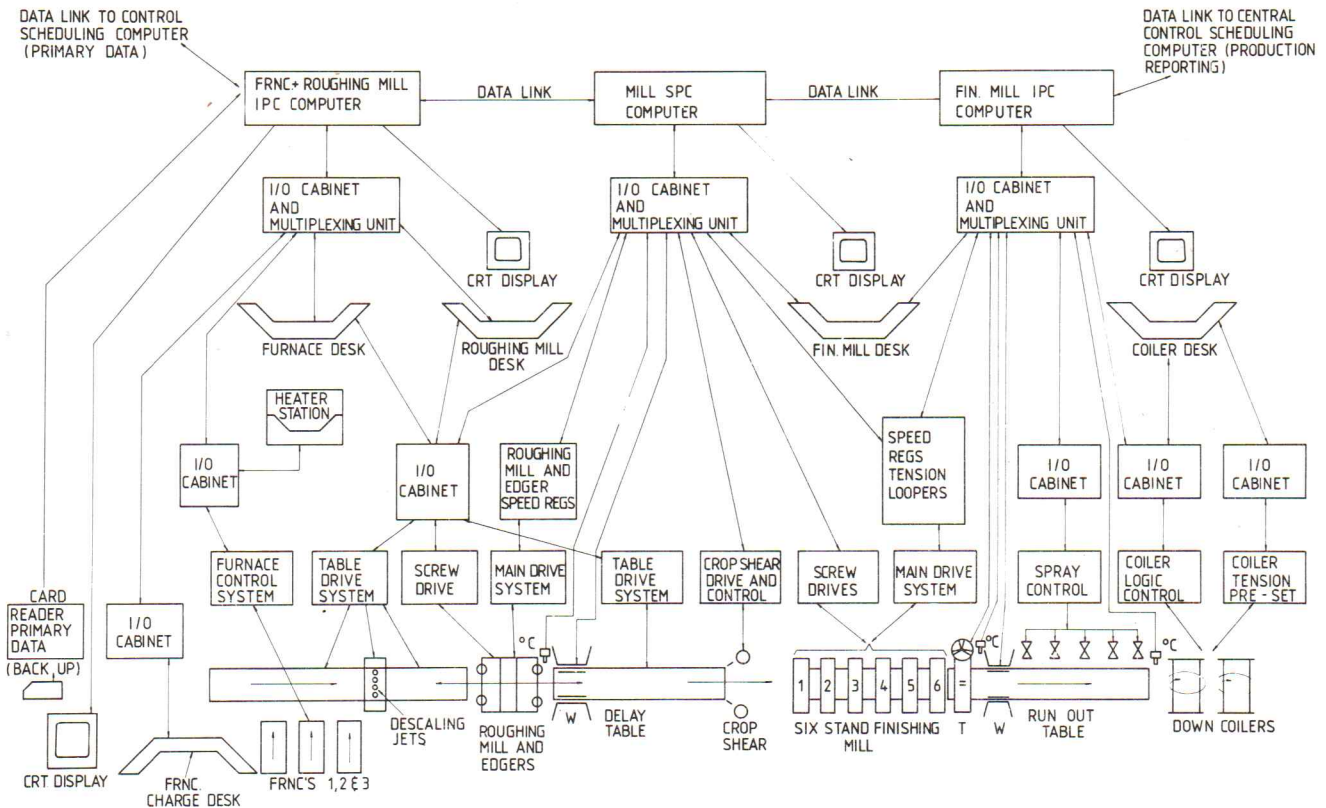
The original system enquiry specification provided for complete process control from furnace entry to coil weighing at the coiler exit with provision for 'bumpless' manual intervention of any or all computer-controlled functions at any time during the rolling process.

The following functions were included in the system: furnace tracking; furnace temperature setpoint control;

mill pacing; roughing mill set-up and control (RSU); edger set-up and control (ESU); finishing mill set-up and adaptive threading (FSU); finishing mill exit temperature set-up and control (FTS, FTC); coiling temperature set-up and control (CTS, CTC); automatic gauge control (AGC); mill tracking from furnace exit to coiler weigh station; production data logging; engineering logging; data communication via data links to central scheduling computer for primary data input and production reporting.

Although the furnace temperature setpoint control function was not included in the initial enquiry specification, it was later included before final adjudication of the tender for the following reasons: possible fuel saving through matching the furnace throughput to mill requirements; quality improvements which can be achieved by reducing finishing mill entry temperature deviations from the desired target for each gauge range.

As engineering and programme development progressed, the operating philosophy separated into two distinct modes. The first, an adaptive Integrated Process Control (IPC), operates with mathematical modelling and continuous parameter feedback; the other uses planned logic and operating modes in Stored Process Control (SPC), which are brought to bear on demand by operator initiative, process sequence or condition and operates with



9 Process control computer system: arrangement of computers, mill equipment, and operators

logic signalling and position regulators. The basic arrangement and functional relationship between the computers, mill equipment, and operators are shown in Fig. 9.

The main reason for the present success of the process control system can be ascribed to full customer participation in system definition, design, test, and installation. Five Iscor engineers and two technicians were sent to the manufacturers for training, software design, manufacture, and complete system simulation test. Of the five engineers, four replaced an equivalent number of the vendor's site personnel which effected a commensurate reduction in the contract price. This involvement of our staff ensured that the interpretation of the system definition by the vendor's engineers and programmers was correct and in line with our operating practice and requirements.

A unique feature of the installation was the integrated pulpit and computer room design. The computer rooms containing the computers, main drive control, and sequencing logics with all the associated interface equipment as well as the pulpits with all the operator stations were manufactured and assembled in the vendor's factory. This enabled complete system check-out and simulation tests to be done before shipment.

The main contractor for the hot strip mill was the mill builder who was made responsible for the whole installation, with the electrical equipment and other suppliers as subcontractors.

The process control equipment and system, however, were negotiated directly with the vendor who was held responsible for meeting the specified performance level, as agreed upon before tender adjudication.

The time taken from mill start-up to when the functions performed to the specified performance levels was four

months. System performance improvements were obtained through fine tuning of the models and no basic model changes have been effected since start-up.

Compared with the manual 1420 mm hot strip mill, the new computer controlled mill enables short rolling schedules, with less than five items per order, to be rolled with better performance in all areas of strip quality.

Management policy regarding the operation of the mill is that all steel is to be rolled under computer control. This ensures the successful operation and continuous improvement of mill performance. The odd occasion when a particular function may be de-selected is during system development. One of the advantages that a computer-controlled mill has over a manually operated mill is that operating practice is defined and consistent so that each function can be analysed against product quality and progressively improved.

Operating results

When discussing and comparing the operating results of the wide strip mill, it is to be said from the outset that the two facilities are not quite comparable. Also, the wide mill has been handicapped by its furnace capacity; only recently has the third reheat furnace come into operation (March 1978). The following figures are representative for the two-furnace operation of 1977 and the limited but significant increases since the commissioning of the third furnace:

- 1 1977 Average monthly throughput: 109 430 t; maximum monthly throughput: 129 913 t; 3-furnace operation (part 1978): 151 580 t (highest yet)
- 2 Average yield: 95.6%, by slab mass calculation; tests indicate that actual average yield is 96.6%.

Table 3 Computer function usage: percentage of total bars rolled (weekly, for 7 months after start-up)

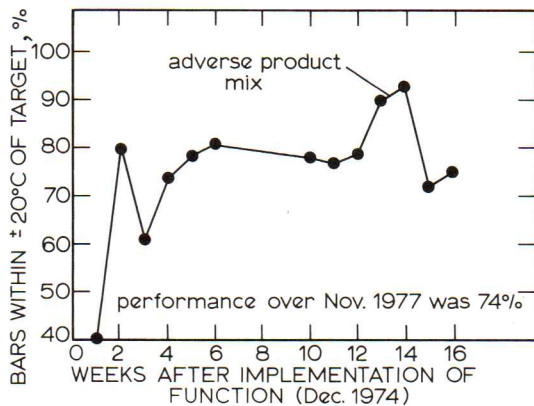
Total bars eval.	Furnace temp.	RSU/ESU	FSU	FTS	CTS	FTC	CTC	AGC	X-ray	Mill pacing
122	NA	100.00	100.00	100.00	94.20	100.00	94.20	NA	NA	NA
510	NA	100.00	100.00	100.00	94.30	100.00	94.30	NA	NA	NA
512	NA	99.20	100.00	100.00	82.30	100.00	82.30	NA	NA	NA
528	NA	100.00	100.00	100.00	92.04	99.79	92.04	NA	NA	NA
944	NA	100.00	100.00	100.00	99.30	100.00	99.30	58.60	98.60	NA
1 106	NA	100.00	100.00	100.00	90.96	100.00	90.95	98.19	98.46	NA
659	NA	100.00	99.33	99.33	84.70	99.33	84.79	93.17	95.30	NA
680	52.00	100.00	100.00	100.00	95.44	100.00	95.44	96.62	100.00	NA
1511	80.10	100.00	99.56	99.56	94.05	97.82	94.05	75.25	99.20	NA
1179	91.50	100.00	100.00	100.00	99.91	99.88	99.91	97.50	100.00	NA
1435	95.50	100.00	100.00	100.00	98.26	100.00	98.26	100.00	98.12	NA
977	84.15	100.00	100.00	100.00	97.54	100.00	97.54	98.82	99.90	NA
2142	80.10	100.00	100.00	99.87	99.58	100.00	99.58	98.98	98.98	NA
1089	59.40	100.00	100.00	99.72	96.80	99.72	96.80	100.00	100.00	71.70
810	66.40	99.38	99.38	99.38	99.14	99.38	99.14	99.75	99.98	77.10
1712	98.50	99.80	100.00	100.00	98.80	99.10	98.80	x	99.50	92.10
1770	95.00	99.70	100.00	100.00	98.50	99.80	98.50	95.60	100.00	95.90
1507	98.60	99.80	100.00	100.00	99.80	100.00	99.80	99.20	100.00	97.20
965	89.40	99.70	100.00	100.00	100.00	100.00	100.00	99.40	100.00	94.50
1269	98.30	98.50	100.00	100.00	96.50	100.00	96.50	99.50	99.90	97.00
1278	82.94	99.70	100.00	100.00	97.40	100.00	97.40	99.20	100.00	96.60
1274	91.00	99.60	99.90	99.90	95.80	99.90	95.80	98.50	100.00	97.50
1833	90.00	99.90	100.00	100.00	97.10	99.80	97.10	97.70	100.00	96.20
1325	94.30	99.50	100.00	100.00	95.80	99.60	95.80	90.00	99.60	85.80
2002	99.20	99.90	100.00	100.00	93.90	98.50	93.90	99.40	99.40	97.20
945	99.90	99.70	100.00	100.00	98.80	99.70	98.80	96.90	100.00	98.60

NA = function not available
 x = no data available

3 Average thickness of strip: 3.3 mm (by mass); minimum: 1.5 mm; maximum: 12.7 mm, for APILX-65 material

4 Net average rolling rate: 260 t/h, or 23 slabs/h for an average slab mass of 11.3 t; maximum rolling rate for 8 h shift: 2821 t; record 24 h rate: 7437 t (January 1978) Three-furnace operation has since yielded a 463 t/h average and 595 t/h maximum rate, while an 8 h output of 3244 t has also been achieved already, with an 8576 t 24 h record rate (May 1978)

5 Strip width distribution, % (by mass): 600–800 mm



10 Furnace temperature control performance (as measured on the roughing mill last pass exit temperature of the bar)

0.8; 801–1000 mm 22.8; 1001–1300 mm 49.8; 1301–1600 mm 18.4; 1601–1950 mm 8.2

6 Set-up thickness accuracy: 98% length of all gauges up to 6.36 mm to within + or – 0.05 mm

Actual thickness, 2 s after the strip leaves stand 6, falls within this accuracy range: 1.5–2.49 mm, 90.6% for 1st bar, 99.1% subsequent bars; 2.5–6.35 mm, 84.9% for 1st bar, 97.3% subsequent bars; 6.36–12.7 mm, 86.3% for 1st bar, 91.8% (± 0.1 mm). (average for period 15 September–15 December 1977).

Width accuracy: for tolerance of + or – 6 mm: 0–1400 mm, 96.3% for 1st bar, 98.4% subsequent bars; 1401–1950 mm, 92.3% for 1st bar, 98.4% subsequent bars

7 Average monthly manned time: 642 h

8 Delays expressed as percentage of manned time: 34.5%

(a) operating delays: 9.7% of which roll changes took 6.9%

(b) service delays: 3.4% of which 'no slabs' took 2.5%

(c) maintenance delays: 21.4% of which electrical 11.9%, automation 1.0%, mechanical 7.5%

9 Material reclassified, as a result of quality defects: 8.0% (temperature, dimensions, surface or coil appearance), of which temperature problems accounted for 5.2%

10 The above output data was obtained with an available total strength of 84 men as direct operating staff, together with 33 men in supporting functions. This strength is approximately 12 below approved book strength for operating staff for three-shift operation of the mill. Book strength for maintenance, shift, and day duty, including

automation and electronics, is 82 as against an average of 66 men actually available.

11 The reheating furnaces operate along the following approximate performance figures:

- (a) heat consumption: 2.5 GJ/t
- (b) fuel: Normally coke-oven and blast-furnace gas mixture
Average heat value for the heating zones is 0.0112 GJ/m³ and for the soaking zone 0.016 GJ/m³
Furnace efficiency is 40% for full hearth coverage at optimum pushing rate.
- (d) furnace exit temp.: 1280°C
- (e) oxygen excess for all zones is held between 3.5–4.0%, with a 2% minimum limit.

12 Roll practice (for all programmes): the roughing mill has flat work and backup rolls. The finishing mill has steel rolls in stands 1 and 2; – 0.1 mm concave (radius) on stand 1 and – 0.05 mm on stand 2. Stand 3 has either steel or iron rolls which are ground + 0.03 mm and + 0.05 mm, respectively. Stands 4 to 6 have iron rolls; stand 4 ground to + 0.05 mm, stand 5 to + 0.02 mm and stand 6 is flat. All finishing mill backup rolls are also flat.

13 The performance of the process control equipment is reflected in Table 3, which shows function usage for the first seven months after start-up.

Problem areas

A significant reduction of the potential output rates for the several product segments is caused by a 'slab provision' which is deficient as to consistency of origin, lengths, and thickness. It is mainly caused by the fact that this mill complex shares its input with the narrow mill. Poor hearth coverage and sudden thickness changes then upset furnace throughput and temperature control. A further problem lies in the gas mixture control. A mixing capacity for four furnaces is in trouble when it has to supply only two furnaces and the mixture has to travel through several kilometres of pipe, with attendant control stability problems. This problem is now much reduced with the current three-furnace operation.

The problem of the slab provision will need the metallurgical capacity extension mentioned earlier to achieve the ultimate target outputs.

The furnace control performance, so far, has also been less successful due to problems in the furnace controllers which prevent repeatability of operation, as well as through the poor slab size mix and hearth coverage in the furnaces. Progress is being made however and the slab exit temperature has been held to within + or – 20°C for 74% of the time during the last few months (see Fig. 10).

Fortunately, the width-control feature of the rougher/edger set-up has coped well with this poor slab supply, but a reduction in output rates has also resulted from this drawback.

Although we have not run into any capacity limitations on the finishing stands, it is clear that the temperature rundown on the tail ends will have a large influence on total capacity, since 30% of our output falls within this thickness and width range at present. The frequent changes of the thickness are certainly detrimental to gauge performance. However, the mill's capability to jump from one gauge to the next and maintain commercial tolerances has been highly satisfactory.

Although finishing mill temperature control has been

good, it is somewhat limited by a speed cone problem, mainly on stand 3, caused by the scrapping of both steel and iron work rolls out of this stand. Roll practice and increased roll consumption can, of course, improve on this, but at an increased cost.

Coiling temperature deviations are still the largest source of temperature 'reclasses'. The main factor again is the small order size, which gives problems with the statistical model for the runout table cooling system which cannot adapt itself and needs correction from the first strip of an order. What must be borne in mind, however, is that such 'reclasses' are in accordance with the strict performance measurement and evaluation by the computer. Some 70% of such 'reclasses' are normally returned to the original orders.

By and large, the number of order changes is the critical factor which affects the quality performance of this mill, a situation which reflects the present order-book situation for internal and export markets.

As regards the equipment, the delay figures again tell their own story. The automation and process control equipment has behaved very well so far and its availability does not normally feature as a constraint on either output or quality. The main mechanical components are likewise satisfactory, except for the coilers where a mandrel problem is persistent. The electrical main drives have given no problems other than the machines on the rougher/edger, where some serious defects have caused significant delays.

In order to achieve full exploitation and maximum output rates for the present configuration (215 500 t/month for 68.7% availability), the following additional features are now proposed.

- (i) automatic roll changing
- (ii) crop shear cartridge
- (iii) third coiler
- (iv) slab yard and coil-storage extensions.

This target capacity will also require an improvement of mill availability which again reflects on roll practice and roll changing, as well as satisfactory coping by maintenance, with increased wear and tear. The former will, as always, be subject to order book make-up. The latter ought to improve as practices and crews settle down and teething problems are overcome. However, the major factor will be consistent slab provision from the continuous slab casters.

The sophistication of the mill and its computer control has, on the whole, been well accommodated by its staff. Indeed, the very challenge of its development has been a spur to enthusiastic support and creative effort. However, as the mill settles down and the more normal routines prevail, it is becoming difficult to sustain motivation. An increase in turnover of knowledgeable and skilled specialists tends to result in the entire mill becoming dependent on a small number of individuals. The continuous training and inspiring of potential successors makes overstaffing and active succession planning a necessity and points to revised job evaluation as a remedy. These are problems that have become evident in many other high-technology areas of endeavour in recent years.

CONCLUSION

Within the limits of a practicable paper, we have tried to give an overall view of our hot strip facilities and results. Many details are, of course, omitted but the main issues have been brought forward. Actual performance figures do

fall short of calculated values. However, the very existence of calculated values makes it possible to evaluate the performance and to analyse problem areas as to cause and remedy.

ACKNOWLEDGMENT

In conclusion, we would like to thank Iscor's Corporate Management for permission to share our experience. We would also like to acknowledge valuable assistance from D.

Rümelin, Superintendent, 2050 mm hot strip mill, A. C. Fokker, Superintendent, 1420 mm hot strip mill, and W. Munting, Superintendent, Electrotechnical Engineering.

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