EUROPEAN COAL AND STEEL COMMUNITY

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Technical Report N° 22

IMPROVING IN WORKING CONDITIONS IN BLAST FURNACES

Source : Ergonomic Team of the Luxembourg Steel Industry
Project N° 1

Author : Dr R. FOEHR

Reference period : 1.7.1971 - 30.6.1974

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1. Introduction

The work of a blast furnace foundryman is strenuous, both because of the inherent effort it requires and because of the heat load imposed on the worker.

Production techniques are constantly evolving. The aim of this development is to increase pig iron production; this result is achieved by extending the duration of the casting operations and increasing the number of draw holes. Up to now technical improvements have generally been brought about by the need to meet certain production requirements. In some instances blast furnace personnel gained the benefit of a reduction in the physiological load at their workplace, but this was a fortunate secondary effect rather than the result of scientific research.

We set out to study and analyse the principal causes of strenuousness in the foundryman's work with a view to proposing technical improvements capable of lightening his work. This research extended over a period of years and fell into three distinct phases :

- diagnosis phase during which the main sources of strenuousness were identified and quantified in order to fix an order of priority for the second phase;
- therapeutic phase aimed at defining the main technical and organisational solutions capable of reducing the physiological load without qualitative and quantitative changes in production;
- implementation and verification phase during which the recommended technical solutions were implemented and their effectiveness verified.

Each of these three phases is discussed in detail below.

2. Identification of the main sources of strenuousness

In order to identify the main sources of strenuousness, we made a comparison of different technical situations at blast furnaces currently operated in the various plants of our company (S.A. ARBED). In this comparison special attention was given to possible correlations between the physiological effort required and the technical solutions adopted. A comparison of this kind should enable the sources of strenuousness to be identified and the degree of strenuousness quantified.

2.1 Method :

Figure 1 (*) outlines the method used to compare the different blast furnace technologies.

Three types of analysis were conducted simultaneously :

1) A simplified analysis of the work;
2) An analysis of the working conditions;
3) A technological analysis of the blast furnace under consideration.

Each foundryman is observed for two complete working shifts. The number of working shifts studied for each blast furnace is therefore between 10 and 12, depending on whether the furnace is operated by 5 or 6 foundrymen.

2.1.1 Simplified work analysis :

This analysis distinguishes between 6 phases in the foundryman's work :

- pig iron remaking phase (tapping pig iron - CF);
- pig iron channel remaking phase (pig iron channel work - TRF);
- slap tapping phase and remaking slag channels (slag channel work - TRL);
- upright position (upright - D);
- seated position (seated - A);
- miscellaneous work during shift (miscellaneous work - TD).

(*) for Figures see Annex

Each work phase is also broken down into its different basic activities, as shown in Table 1. Every minute an observer notes the code corresponding to the dominant activity during that minute. On the basis of this minute by minute record, the mean duration of the different activities can be estimated.

2.1.2 Analysis of working conditions :

The purpose of this analysis is to quantify the total work load and total heat load experienced by operators at the different blast furnaces. It also enables the work loads corresponding to each phase and activity listed in Table 1 to be estimated.

Continuous telemetric recording of the cardiac frequency was used to measure the physiological load. With a recording of this kind, the work loads and heat loads experienced by an operator at his workplace can be evaluated (VOGT J.J., FOEHR R. and colleagues). Figure 2 outlines the principle of this method.

The stresses are estimated as follows during calibration of the operator :

a) - motor stress, by taking account of positive work only;

b) - thermal stress, by calculating the evaporation required to maintain homeothermy (METZ 1967).

The physiological strains are evaluated in terms of circulatory strains equivalent to the strain imposed by pedalling an ergometric bicycle for the workload, or to the strain experienced in a climatic chamber for the heatload. The values are measured in equivalent kJ for the workload and in kcal equivalent required evaporation for the heatload.

2.1.3 Technological analysis of blast furnaces

The main technical characteristics of the 5 blast furnaces studied in this article are summarized in figure 3. They can be classified in two categories : topographic characteristics and functional characteristics.

The following topographic characteristics were used :

- diameter at furnace hearth d(m);
- useful height of furnace h(m);
- total length of pig iron channels L(m);
- total length of slag channels L'(m);
- number of draw holes;
- number of slag holes;
- angle of inclination of pig iron channels (α as %);
- angle of inclination of slag channels (α' as %).

A movable main channel was installed at the blast furnace S2. This channel does not require hot remaking between casting operations but can be remade in the cold state at 15 day intervals. Slight surface cleaning is all that is necessary between casting operations.

The following functional characteristics were used :

- pressure inside the blast furnace (p in kg/cm2, either natural p = n or increased : back-pressure with value shown in figure 3);
- mean pig iron production (P in tons per shift);
- mean slag production (P' in tons per shift);
- number of pig iron casting operations (N in number per day);
- mean duration of pig iron casting operations (D in hours).

Comparison of these three analyses should enable the main sources of strenuousness to be detected and the principal methods of improving working conditions defined. The correlations between the physiological burden imposed during certain work phases (see 2.1.1 and 2.1.2) and the topographic or functional technical characteristics (2.1.3) must identify the sources of difficulty.

2.1.4 Number of recordings taken

A team of foundrymen comprises four categories of foundryman. The first foundryman is responsible for the work of the team as a whole. He supervises operation of the blast furnace (HF) and taps the pig iron. The second foundryman assists the first in tapping and replugging the furnace. He prepares the machines used for these two operations. The third and fourth foundrymen are primarily responsible, with the second, for remaking the pig iron channels and evacuating the slag. A team comprises these four categories, one or more of which may be represented by more than one individual. Table 1 shows the composition of the different teams studied. The work done by each foundryman is specific to his category. To ensure that our analysis covered the entire workload and heatload, we made two recordings for each category. Table 1 shows the total number of recordings made.

Plant Category	D	B_1	B_2	S_1	S_2
1st foundryman	1	1	1	1	1
2nd foundryman	1	1	1	1	1
3rd foundryman	1	1	2	2	2
4th foundryman	2	2	2	2	2
TOTAL	5	5	6	6	6
Number of recordings	10	10	12	12	12

Fifty six recordings lasting for eight hours each were therefore taken during the diagnosis phase.

2.2 Results

2.2.1 Duration of the different activity phases

The simplified work analysis referred to in 2.1.1 enables us to determine the average time devoted by each category of foundryman to each type of activity. Without considering each basic activity in detail, we shall simply determine on the one hand waiting time (upright and seated) in relation to the duration of the activity as such, and on the other the importance of the pig iron casting phase in the actual activity time.

The percentage of the total presence time represented by waiting in the upright or seated posture is shown on the ordinate of figure 4. On average, operators are waiting for 40 % of the time of their presence; half this waiting time is spent in the upright position and half seated. The installation of a back-pressure system at B2 and S2 increased this waiting time by some 10 %. This increase is due to a more regular slag flow.

This is confirmed by figure 5 which shows that the time devoted to pig iron casting is reduced by some 10 % between B1 and B2 and between S1 and S2.

The results relating to the durations of activity lead to the conclusion that for

- 20 % of the time the operator is waiting in an upright position;
- 20 % of the time he is waiting seated;
- 25 % of the time he supervises the pig iron casting;
- 20 % of the time he is engaged on remaking the pig iron channels;
- 15 % of the time he is engaged on drawing off the slag and remaking the slag channels.

2.2.2 Motor and thermal stresses experienced throughout the working shift

On the basis of the continuous recording of cardiac frequency taken throughout the shift, we determined first of all the total cardiac extrapulsations in relation to the initial state of rest. These cardiac extrapulsations can be divided into two groups : thermal cardiac extrapulsations (EPCT) caused by the heatload on the operator, and motor cardiac extrapulsations (EPCM) caused by his workload.

Figure 6 shows the mean inter-individual EPCT and EPCM values for the five situations. These two values are added together. The total cardiac extrapulsations (EPCT + EPCM) are always less than 40 beats per minute. This value is considered permissible for a shift of 8 hours per day. For all 5 situations together the EPCT represent 2/3 of the EPCM. Examination of the total circulatory load on all the foundrymen shows that 2/5ths of the total is due to the heatload and 3/5ths to the workload.

The method of measuring the workloads and heatloads on an operator enables the EPCT and EPCM to be converted into equivalent thermal stresses and equivalent motor stresses respectively. These two types of stress are analysed below.

2.2.2.1 Equivalent thermal stresses :

Figure 7 shows the mean equivalent thermal stresses on the operators in the 5 technological situations studied.

The thermal stresses at blast furnaces D, B2 and S1 are very similar. Although the platforms of blast furnaces B1 and B2 are both badly ventilated and orientated, the equivalent motor stress is high at blast furnace B1 only. This observation can be explained by the existence of back-pressure in blast furnace 2 of factory B (technical difference which also exists between S2 and S1). A back-pressure system results in a more regular flow of pig iron which gives a reduction in the number of interventions by foundrymen during the casting operation and consequently a lower exposure to infra-red radiation. This reduction leads to a substantial decrease in the equivalent thermal stress. The provision of back-pressure at B2 partly compensates the poor ventilation of this platform. The reduction in thermal stress is greater between S2 and S1 than between B2 and B1 because at S2 we have installed, in addition to the back-pressure system, an interchangeable main pig iron channel (4 first metres after the draw hole). The main channel no longer requires remaking after each casting operation. The resulting reduction in workload is reflected in the equivalent thermal stress. In order to reduce the thermal stress it is therefore necessary to influence the two main sources characterizing this stress : the ambient temperature and the workload.

2.2.2.2 Equivalent motor stresses :

Figure 8 shows the total work necessary to ensure operation of the blast furnace. In this figure the total work is divided into several parts, each corresponding to an activity phase.

With the exception of blast furnace S2, the composition of the total work is as follows :

- 3/5ths for pig iron production, i.e. :
  - 1/5th expended during the casting phase;
  - 2/5ths expended on remaking the channels;
- 1/5th for slag production;
- 1/5th for miscellaneous activities and waiting in the upright position.

The total work performed is the greater the higher the production of pig iron and slag. We shall compare the total work performed with the technical characteristics in order to detect the main causes of this workload. The comparison will be made separately for pig iron and slag production.

2.2.2.2.1 Equivalent motor stresses required by pig iron production

The upper third of figure 8 represents the equivalent motor stress required by pig iron production. It corresponds, for each factory, to the sum of the stresses in the casting and pig iron - channel work phases shown in figure 8. In the first stage, we shall make a comparison with an operating characteristic, i.e. pig iron production. This is shown in the median section of figure 9. The lower third of this figure corresponds to the equivalent motor stress required by the production of one ton of pig iron. The dispersion of the values is smaller, reflecting the influence of pig iron production on the motor stress. However, there are considerable inter-factory differences.

In a second stage we compared the motor stress required by the production of one ton of pig iron with a topographic characteristic : the total length of the pig iron channels. This comparison is shown in figure 10. In the lower third of this figure we note that the motor stress required per ton of pig iron and metre of channel is a constant for blast furnaces D, B1, B2 and S1. The reduction observed at S2 is due to the interchangeable main channel whose maintenance requires less work (see 3.2.1). With the exception of situation S2 no progress has been made in regard to the channel remaking work. The other channels all have qualitatively the same design and configuration;

they all require the same type of work for remaking.

This analysis shows that it is possible to influence two topographic parameters of the casting platform : the length of the channels and their design. The motor stress is directly proportional to the length of the channels. The coefficient of proportionality is imposed by the design and configuration of these channels.

2.2.2.2.2 Equivalent motor stresses required by slag production

The upper third of figure 11 represents the equivalent motor stress required by slag production. In the median third of this figure, an operating characteristic is shown, namely slag production per shift. The lower third of this figure corresponds to the equivalent motor stress required to produce a ton of slag.

The work required per ton of slag at blast furnaces D and S1 is identical : the production technique is the same. These two blast furnaces in fact have only one slag tap extended by a channel with a length of approximately 25 metres. In these two furnaces the total work required for the production of pig iron is proportional to slag production.

At the three other blast furnaces the work required per ton of slag produced is much smaller. Blast furnaces B1 and B2 have as their principal technical characteristic the fact that the blast furnace has several slag taps (5 for B1 and 3 for B2), extended by short channels with a very steep angle. This solution is extremely favourable. At blast furnace S2 the slag is produced solely in the form of casting slag. This solution which can be adopted when rich ore is available (producing only a small quantity of slag per ton of pig iron) is ideal in terms of a reduction in equivalent motor stress.

2.2.3 Equivalent mechanical powers required for the different activity phases :

On the basis of the continuous cardiac frequency recording (2.1.2) associated with the simplified work analysis (2.1.1) we were able to estimate the equivalent mechanical power required for each basic activity listed in Table 1.

Strenuous activities requiring an equivalent mechanical power greater than 100 watts include :

- cleaning pig iron channels by hand (activity 4);
- sanding the channels (activity 8);
- cleaning the slag channels (activity 14);
- unforeseen incidents (activity 18).

Light activities requiring an equivalent mechanical power of less than 50 watts include :

- supervising the casting operations (activity 1);
- unplugging and replugging the blast furnace (activity 3);
- supervising the slag tapping (activity 12);
- waiting in the upright posture (activity 16).

All other activities can be treated as medium.

2.2.4 Inter-individual distribution of equivalent motor stresses

Figure 12 shows the equivalent motor stress for the different categories of foundrymen at different blast furnaces. There is a wide dispersion between individual foundrymen at all blast furnaces except

B2 : a more equitable distribution of the motor stress is desirable.

The distribution of activities imposed on each foundryman must be modified whenever the production technique is changed. To take an example, analysis shows that only the 4th foundryman benefits from a reduction in work on the transition from tapped slag production (S1) to cast slag production (S2). At S1 the 4th foundryman had the heaviest workload. Whenever production techniques are changed a new distribution of activities should be envisaged or at least the existing distribution examined to make sure that it does not give rise to an unbalanced sharing of the load.

2.3 Discussion and conclusions of the diagnosis stage

The results as a whole enable us to identify the main problem factors and their quantitative importance in the physiological load to which operators are exposed. Figure 13 shows in outline the results of this diagnosis stage.

For the shift as a whole, the total circulatory load on the foundrymen is on average 24 beats per minute. 2/5ths of this load stem from the thermal stress which is both endogenous (work) and exogenous (radiation).

3/5ths of the total circulatory load originate from the motor stress. The latter is composite : pig iron production accounts for 2/5ths due to the motor stress, and slag production for the final fifth due to this stress.

The motor stress corresponding to pig iron production is a function of the quantity of pig iron produced and, for a given quantity, proportional to the length of the channels. The structure or quality of the channels is also an important factor in the configuration of the system liable to modify the thermal stress. Depending on the configuration of the channels and their quality, the strenuousness of remaking work will vary.

The motor stress corresponding to slag production is a function of the quantity produced. For a given quantity this work may be determined in large measure by the type of slag production (tapped or cast slag) and in the case of tapped slag production by the number of taps on the blast furnace and the length and slope of the channels.

The bulk of the motor stress included in the "miscellaneous" category in figure 13 is accounted for by waiting in the upright posture (see figure 8).

In addition to these strictly technological causes of equivalent motor stress there are also organizational causes, in particular the distribution of the total motor stress between individual foundrymen.

On the basis of these results it is possible to define technologies capable of improving the working conditions of blast furnace foundrymen.

3. Techniques capable of reducing motor and thermal stresses :

On the basis of the results shown in figure 13, we designed technical solutions capable of reducing the physiological load imposed on operators. The main factors determining circulatory loads are listed in the right-hand section of the figure.

Intervention of these factors may diminish the equivalent stresses undergone and consequently reduce the circulatory load.

3.1 Reduction in equivalent thermal stress :

Radiation is an important factor in determining the circulatory load of thermal origin. This radiation acts both during casting operations and during the channel remaking work. A reduction in the radiant thermal flux may be obtained by a greater channel depth or by covering the channels.

A greater channel depth would reduce the radiant load primarily during casting operations since operators could position themselves in a "shadow zone" while still being close enough to the channels for effective supervision. An increase in the channel depth would on the other hand increase the strenuousness of the remaking work and consequently the circulatory load of motor origin.

Covering the channels is an ideal solution if it is technically feasible. Covering also enables the remaking work to be lightened as we shall see later.

3.2 Reduction in equivalent motor stress

A reduction in the workload would have two advantages; it would reduce the metabolic thermal load (hence the circulatory load of thermal origin) and also the circulatory load of motor origin. To reduce the quantity of work required for operation of the blast furnace, intervention is possible at 3 points as shown in figure 13 : the work required for pig iron production which is quantitatively the most important; the work needed for slag production and the work under the "miscellaneous" heading. The latter is of the same order of quantity as work required for slag production; together these two types of work account for one third of the work required for pig iron production.

3.2.1 Reduction in equivalent motor stress required by pig iron production :

As shown in figure 13 the reduction in work required by pig iron production can be obtained by a reduction in the quantity of pig iron produced. This is not the optimal point of intervention. However, it should be noted that any increase in pig iron production leads to a proportional increase in the work required of the team of foundrymen.

The most effective point of intervention is the configuration of the production system. Two factors can be modified : the length of the channels and their quality. The channel length can be reduced by a suitable design of the platform. The installation of pig iron tipper cars at the end of the channels enables the Y junctions which exist on all blast furnace platforms to be eliminated and the total length of the channels consequently reduced by several metres. A careful study of the capacity of the pig iron ladles also enables the number of tippers to be reduced. If the time taken to replace a ladle is less than its filling time it will generally be possible to use a single tipper. The total length of the channels can therefore be reduced and there will be a corresponding reduction in work.

The quality of the channels is a decisive factor in determining the motor stress on foundrymen. The type of channel lining does not substantially change the quantity of work required for channel remaking : the work needed per ton of pig iron and metre of channel is much the same in situation D and situation S2, the type of lining being different. The aim must be to eliminate the need for systematic remaking in the hot state with cold remaking at given intervals. A solution of this kind can be envisaged if the channels are covered as proposed earlier to reduce the radiant heat flux to which foundrymen are exposed : a suitable covering must enable the temperature of the channels to be maintained at a level such that successive casting operations can be carried out normally. We examined this solution which has now been implemented on one of our platforms.

3.2.2 Reduction in equivalent motor stress required by slag production

A reduction in slag production work can be obtained by reducing the quantity of slag produced. The solution of maintaining or increasing pig iron production while reducing slag production had been rendered possible by the use of a rich ore. This is the case for blast furnaces S1 and S2. This solution has not been generally adopted. Depending on whether rich or poor ore is used it is possible do reduce the workload by appropriate adaptation of the blast furnace.

The use of rich ore is also interesting from the angle of motor stress. On the one hand the production of slag per ton of pig iron produced is very low. On the other it is possible to generate this slag in the form of casting slag only : the production of casting slag is the most economical process as regards the motor stress imposed on the operations per ton of slag produced.

In comparison with rich ore, the use of poor ore results in a greater workload for the same pig iron production. The installation of several slag tap units extended by short channels at a steep angle enables this workload to be reduced to a significant degree.

Finally the upright posture represents some 8 % of the total circulatory load. It is primarily due to the fact that the operator must remain standing to supervise the work platform correctly. The installation of raised observation posts at which the operator can be seated would certainly be very effective.

4. Practical solutions and verification of their effectiveness :

4.1 Description of the technical solutions :

On the basis of the various technical designs envisaged we created two new technological situations. These are derived from the situation S2 which has since undergone two series of modifications, primarily at the level of the casting platform.

The situation S3 differs from situation S2 solely in respect of the pig iron channels. These are wider and deeper in situation S3. They consist of prefabricated, interchangeable components. The channels require periodic remaking. Their length has been reduced as far as possible by installing pig iron tipper cars which replace the conventional hoppers at the end of the channels. The total length of the pig iron channels which was 30 metres in situation S2 has been reduced to 20 metres in situation S3.

In situation S4 we completely covered the secondary channels. The operator is no longer exposed to radiation from the liquid pig iron during the flow from the blast furnace to the pig iron ladles.

4.2 Validity of the technical solutions :

Since these solutions were implemented we have taken a number of physiological measurements. Situation S3 was studied in great detail as we recorded 16 shifts here (two shifts for each of the 8 foundrymen). The comparison method shown in figure 1 was used (see 2.1).

A brief study was made of situation S4. For this purpose we made only two complete 8 hour recordings. Despite the small number of recordings the results obtained are given below.

Looking at the equivalent thermal stress on the operators we find, from the results shown in figure 14, that it is considerably reduced in situation S3. The two recordings made at blast furnace S4 show the beneficial effect of covering the channels. If this effect is not clearly apparent in this figure, the reason is that we only took recordings for the first 2 foundrymen whose work is not substantially changed by this technical modification. In the view of all the operators, situation S4 represents a very real improvement over situations S3 and S2.

The equivalent motor stress on the operators is also shown in figure 14. It is expressed in kJ of work provided by an operator during a shift. In situation S2 the pig iron production is 840 tons per shift and the slag production 260 tons per shift. Each foundryman does an average of about 1100 kJ of work. In situation S3 production is 1400 tons pig iron and 400 tons slag per shift. The personnel strength is increased from 6 to 8 persons. Production has therefore increased by 65 % while the number of staff has risen by only 33 %. As shown in figure 14, the work requirement has risen by 13 %. The technical improvement in situation S3 therefore represents a benefit in terms of equivalent motor stress of some 20 %.

Situation S4 offers certain additional improvements. Figure 10 shows a reduction in the equivalent motor stress on each operator. This reduction is slight. It applies only to two recordings made on the 1st foundrymen. The activity to have undergone the principal modifications is channel remaking. The first foundryman takes very little part in this. It is therefore normal for figure 14 to show only a very slight reduction in the equivalent motor stress. In the view of all the foundrymen, situation S4 represents a real progress over situations S3 and S2 from which it has been developed. A further development is in progress at present. In addition provision has been made for total aspiration of the fumes emitted above the pig iron ladles during casting operation. This aspiration will be facilitated by complete covering of the pig iron channels. The suction hoods will be installed above the pig iron ladles.

Observation posts will also be installed on the platform enabling the operators to supervise the production process from a seated position.

4.3 Other effects of these technical solutions :

The technical solutions adopted for situation S3 and even more so for situation S4 enabled the number of minor and serious accidents to be reduced by 50 %. In situation S4 no burns at all were observed. Benign eye lesions were also reduced considerably.

Successive increases in production have not led to an increase in the total load on the foundrymen. Thanks to technical improvements made by the chief engineer and his assistants there has even been a distinct advance on the previous situation for foundrymen.

5. Conclusions

This study demonstrates the value of ergonomic analysis of an industrial situation. It enables the main problem factors to which operators are exposed to be determined. On the basis of this analysis it is then possoble to define the various technical solutions and evaluate their theoretical benefits in terms of physiological loads.

Three stages of research were necessary to arrive at an improvement of working conditions at blast furnaces. The analysis of working conditions is conducted in terms of equivalent circulatory loads. These loads are measured by continuous telemetric recording of cardiac frequency. In practice the physiological strain is the easiest to measure. Technical processes capable of reducing the physiological load factors are designed on the basis of this first diagnosis stage.

The technical solutions used in our study enabled a reduction to be achieved in the thermal stress due to radiation of the liquid pig iron and in the motor stress linked mainly with the production of this pig iron.

These technical solutions are accompanied by other effects such as a reduction in the number of minor and serious accidents.

The financial cost of such a study and the resulting technical solutions is high. Financial support from the EEC helped to reduce this cost. In addition the results of this research can be used by design offices when planning new blast furnaces and the workplaces of blast furnace foundrymen.

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A N N E X

FOR EACH TECHNOLOGICAL SITUATION
I. E. FOR EACH BLAST-FURNACE

WE PERFORME { DURING THE 8 HOURS SHIFT WE DETERMINE TWICE FOR EACH OPERATOR } FOR EACH OPERATOR

1. JOB ANALYSIS
   - A. DIFFERENT ACTIVITY PHASES
   - B. DIFFERENT ENVIRONMENTAL CONDITIONS
2. SURVEY OF WORKING CONDITIONS
   - A. METABOLIC STRESS
   - B. THERMAL STRESS
3. TECHNOLOGICAL SURVEY OF BLAST-FURNACE
   - A. CONFIGURATION OF SYSTEM
   - B. OPERATING CONDITIONS OF SYSTEM

QUALIFICATIONS	NUMBER
1st FOUNDRYMAN	1
2nd FOUNDRYMAN	1 or 2
3rd FOUNDRYMAN	1 or 2
4th FOUNDRYMAN	1 or 2

Figure 1 : Record of experiments

ANNEX

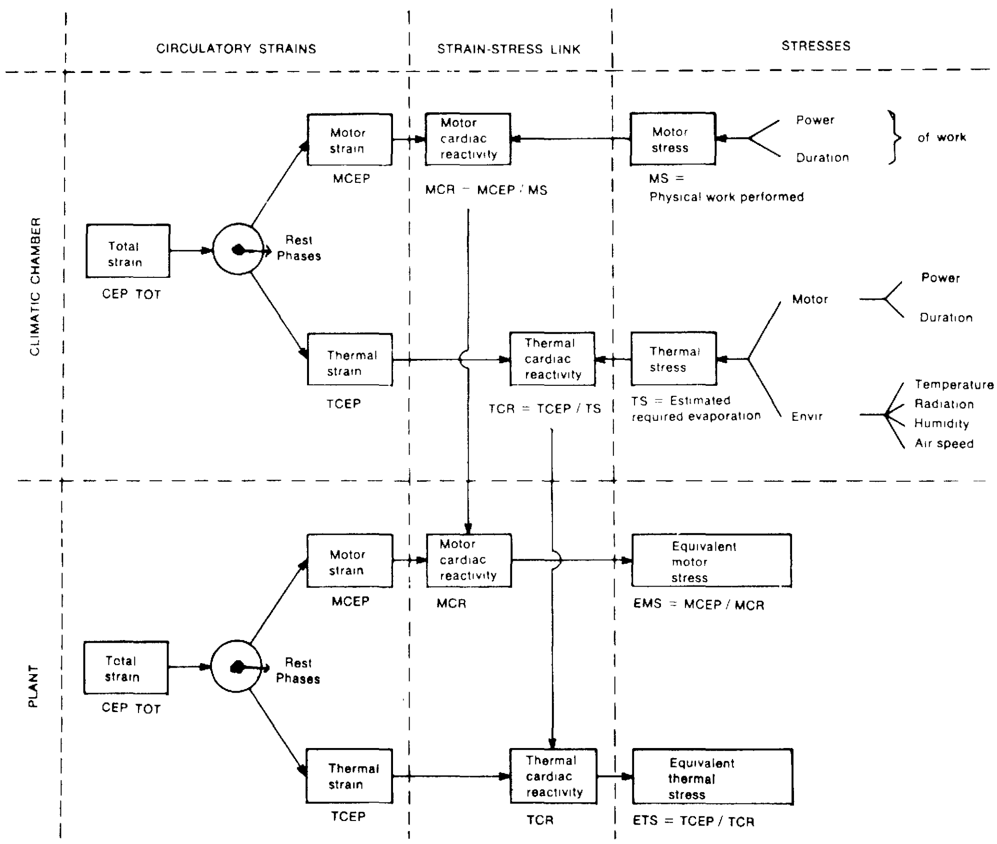

Figure 2 : Block diagram of method of measuring thermal and motor stresses.
Arrows indicate operations to be carried out successively.

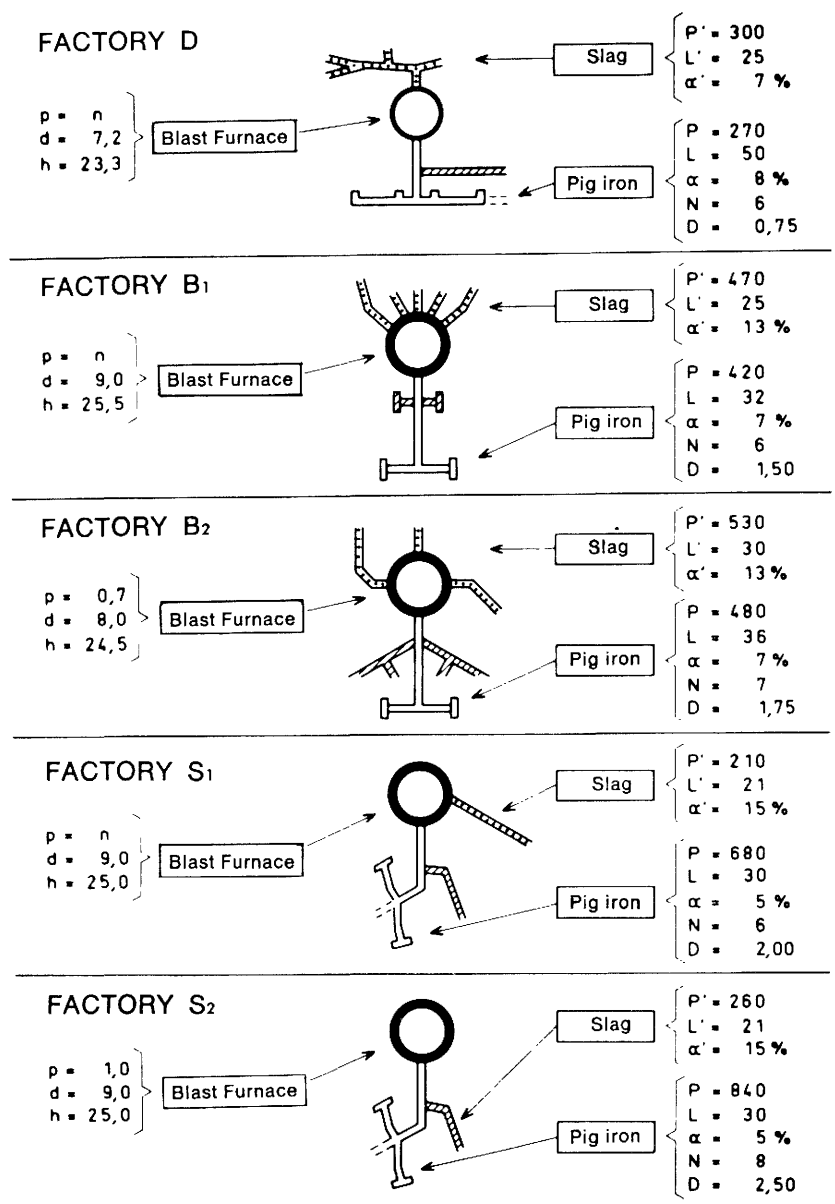

Figure 3 : Technological characteristics of the 5 blast furnaces studied at 3 factories D, B and S (p = pressure to be maintained in blast furnace; n = natural; d = diameter at hearth in metres; h = useful height in metres; P' = slag production in tons per shift; L' = length of slag channels in metres; α' = slope of slag channels; P = pig iron production in tons per shift; L = length of pig iron channels in metres; α = slope of pig iron channels; N = number of pig iron casting operations per 24 hours; D = mean duration of pig iron casting operation in hours).

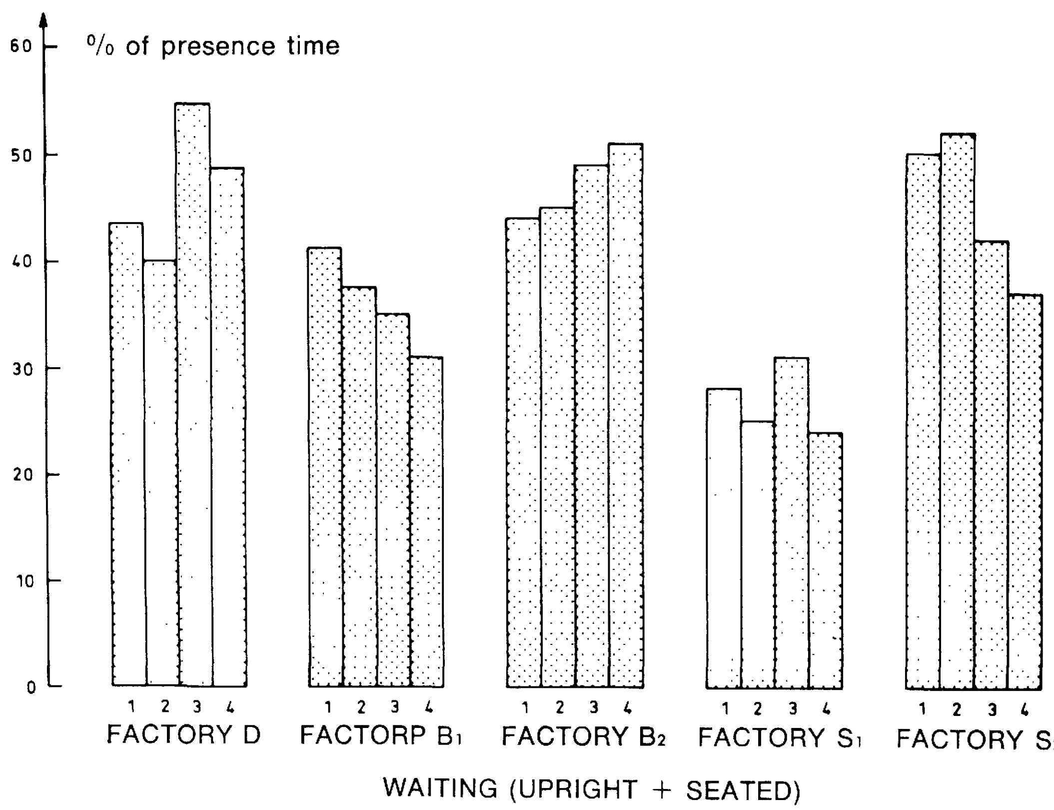

Figure 4 : Time of presence in factory (as %) during which the operator is waiting in the upright or seated position. Each column numbered from 1 to 4 corresponds to a category of foundryman.

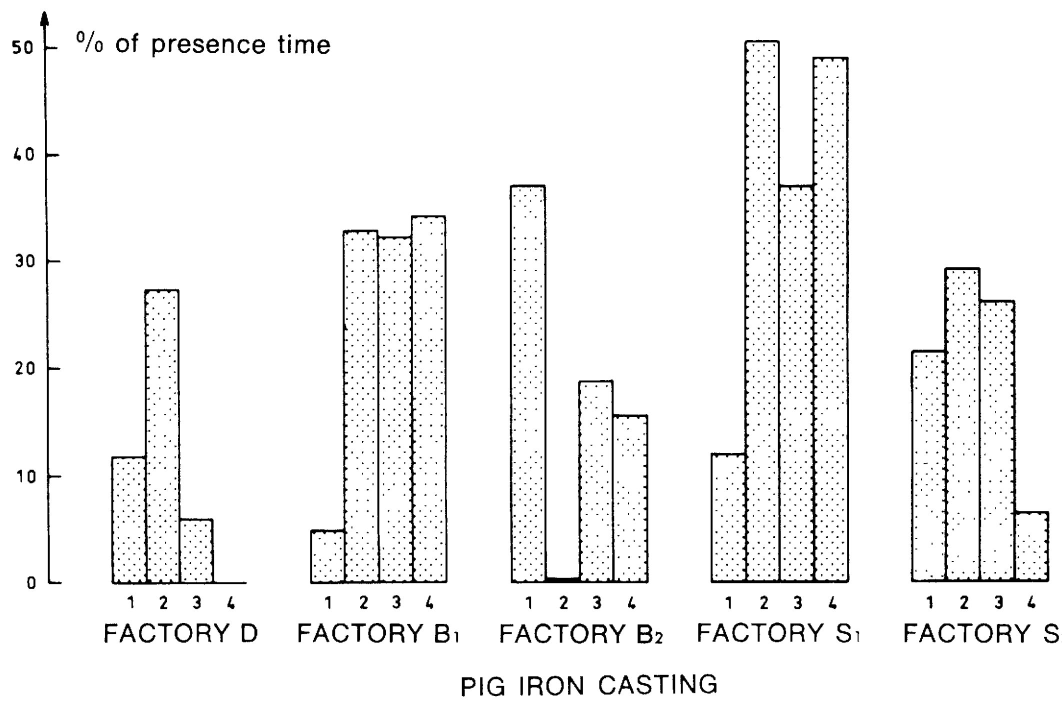

Figure 5 : Time of presence in factory (as %) during which the operator is engaged on pig iron casting. Each column numbered from 1 to 4 corresponds to a category of foundryman.

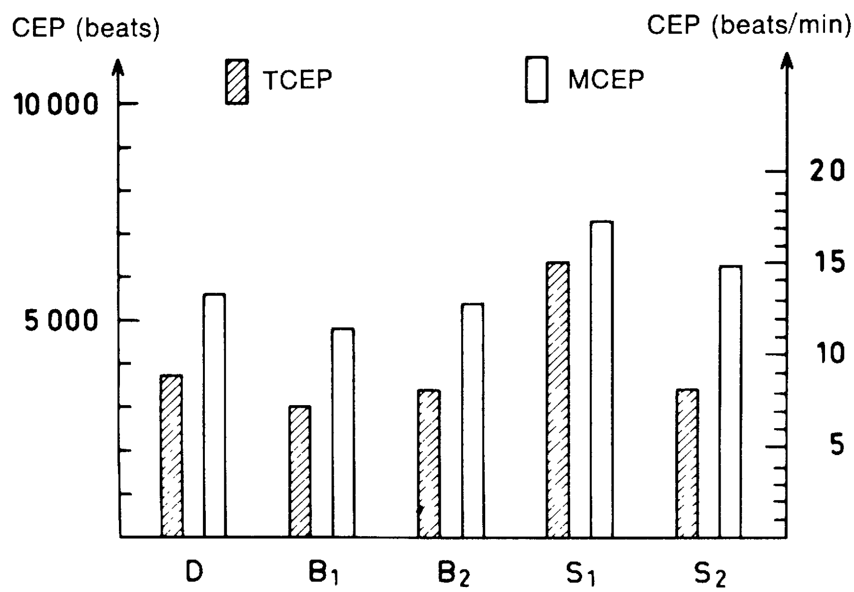

Figure 6 : Thermal cardiac extrapulsations (TCEP) and motor cardiac extrapulsations (MCEP), as a total (left-hand ordinate) and by minute (right-hand ordinate) observed in the 5 technical situations studied.

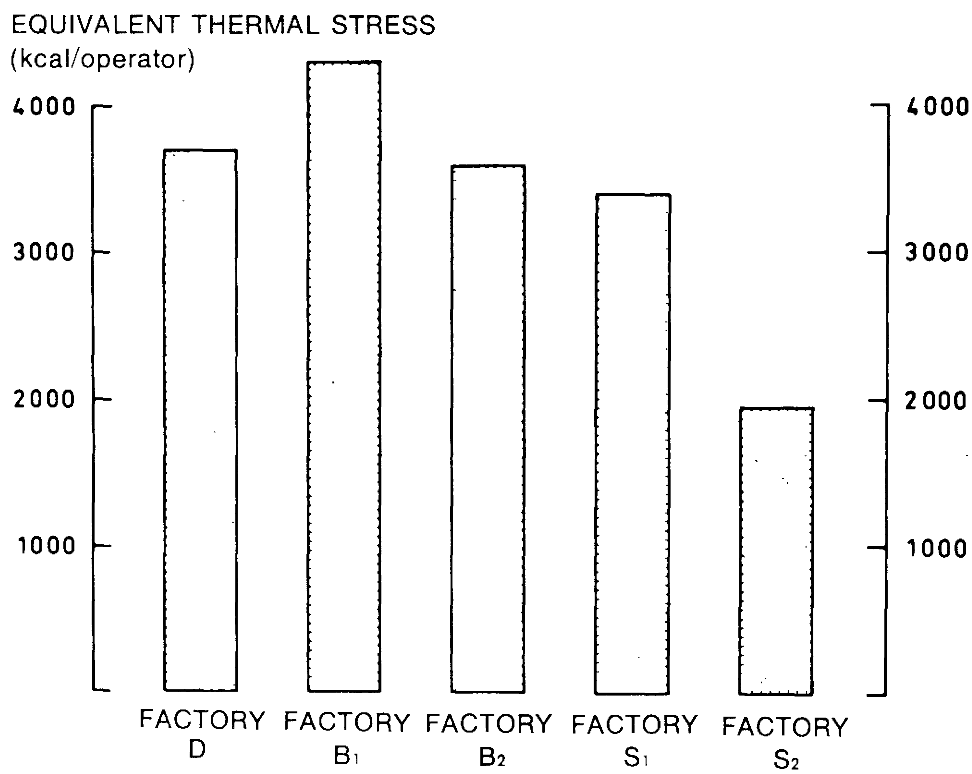

Figure 7 : Equivalent thermal stresses observed at the 5 blast furnaces of factories D, B and S.

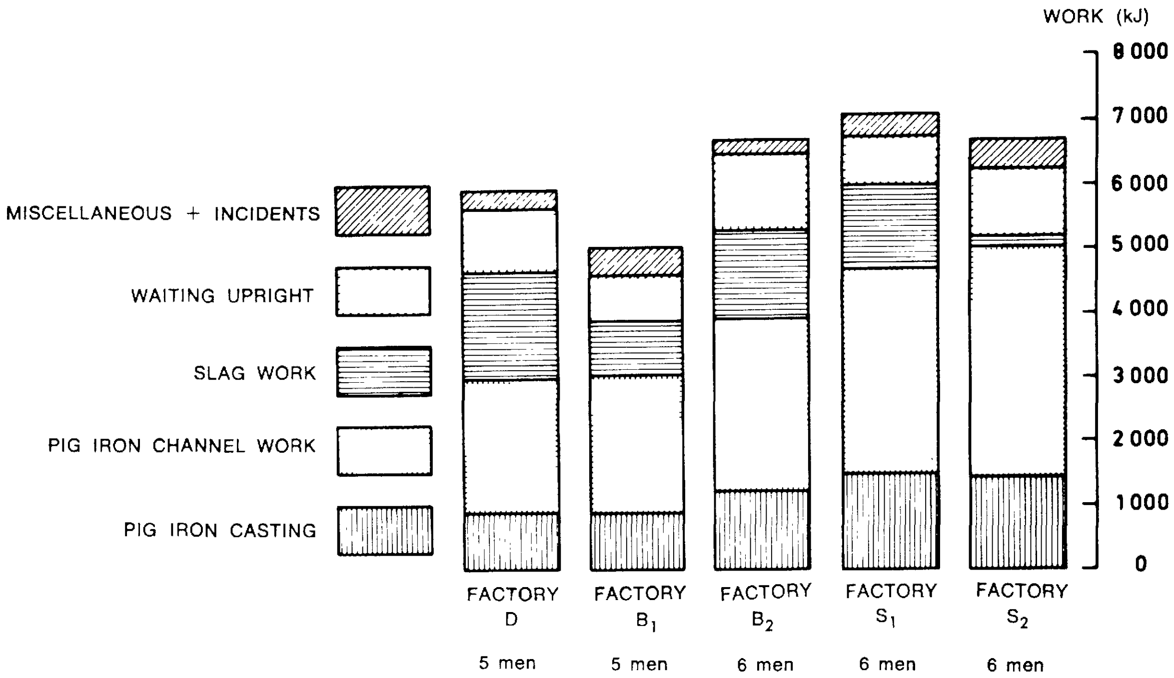

Figure 8 : Total equivalent motor stresses observed. The corresponding components for the different activity phases are indicated for each blast furnace.

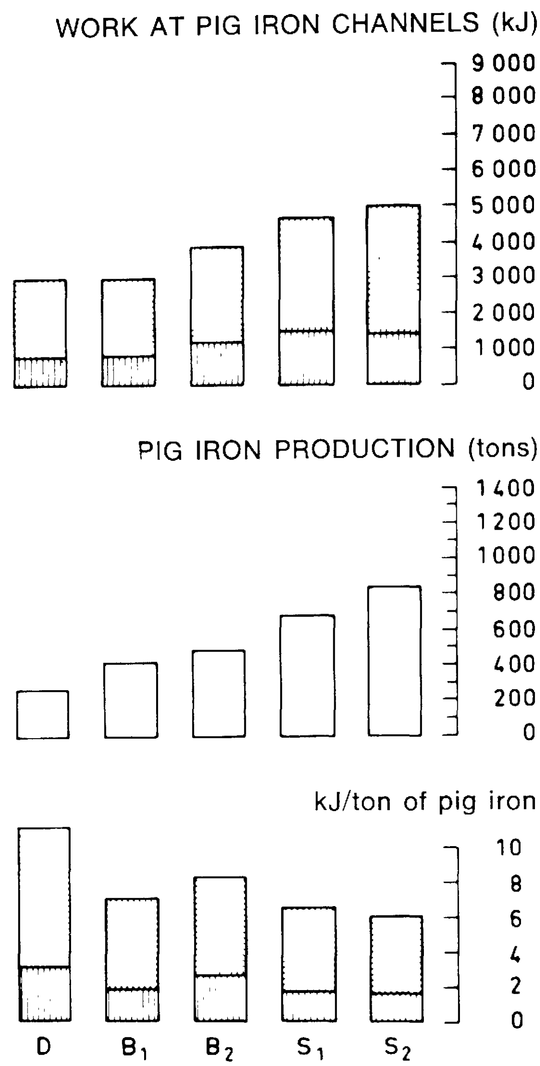

Figure 9 : The upper third represents the total work required for pig iron production (pig iron channel work phase and casting phase, see fig. 8). The median third represents pig iron production and the lower third shows the relationship between these two values.

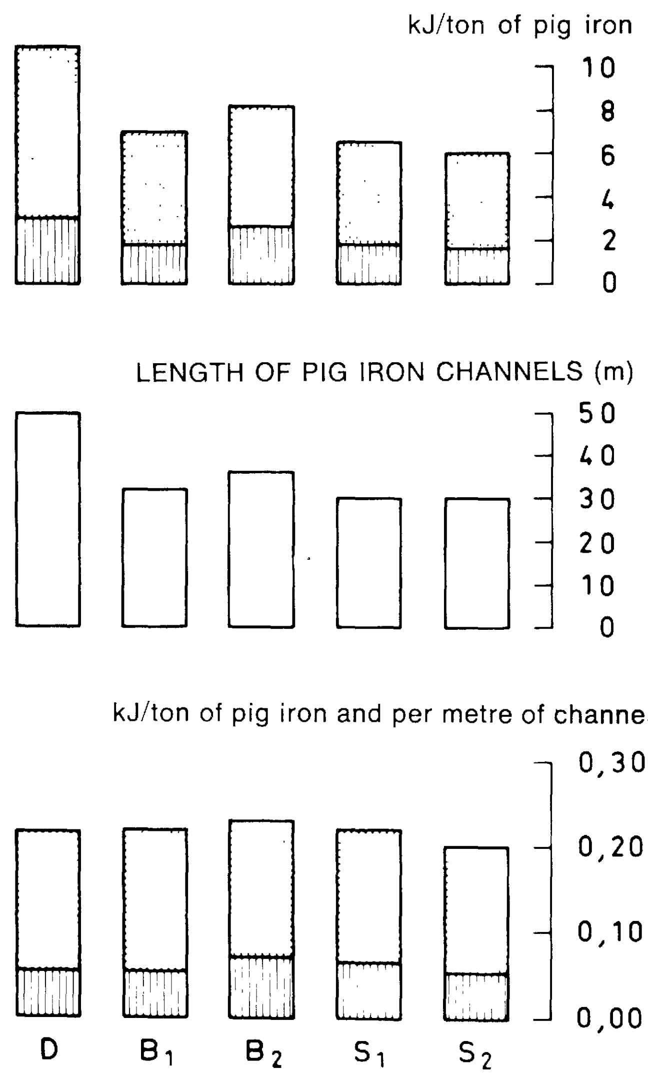

Figure 10 : The upper third of this figure represents the quantity of work required for the production of one ton of pig iron (identical to the lower third in figure 9). The median third corresponds to the length of the pig iron channels. The lower third represents the relationship between these two values.

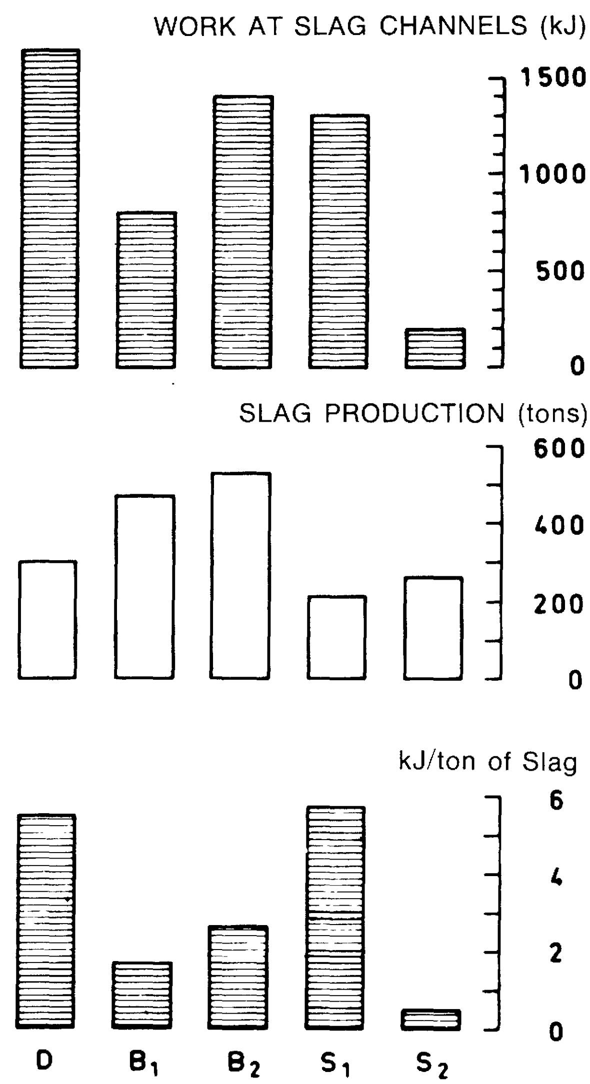

Figure 11 : The upper third of this figure represents the work required at each blast furnace for the production of slag. The median third corresponds to slag production and the lower third shows the relationship between these two values.

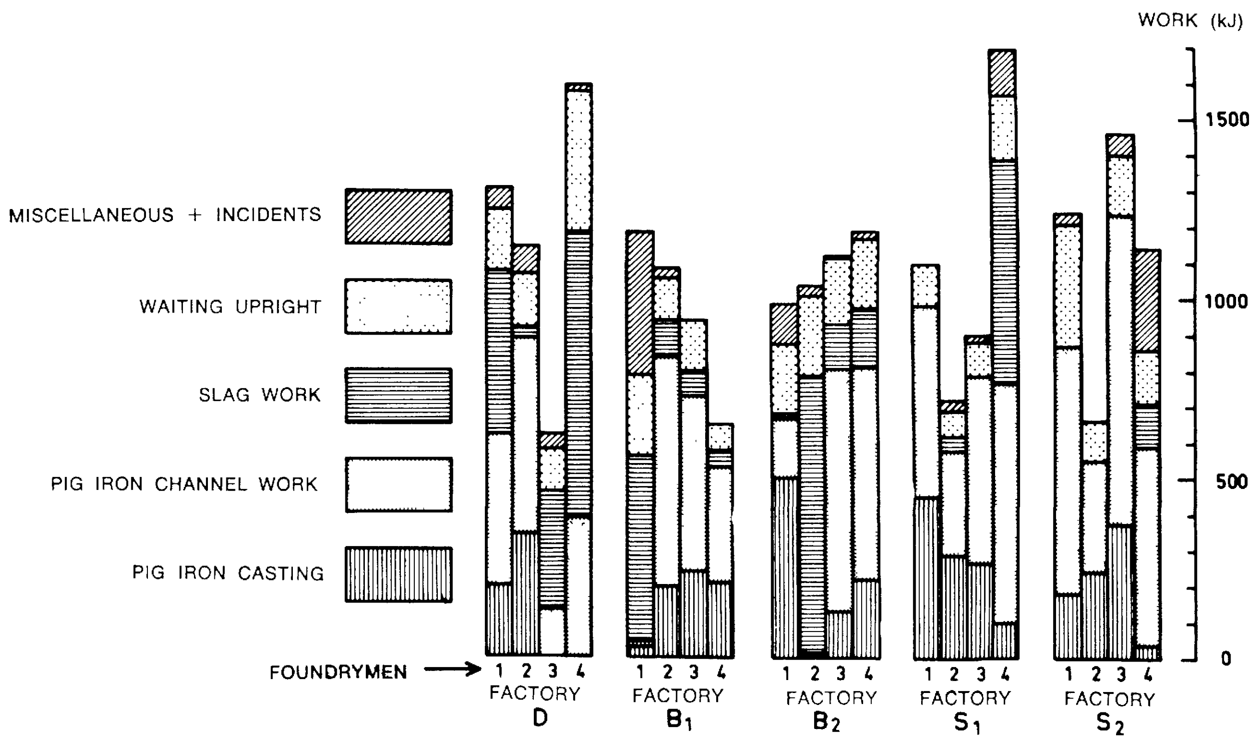

Figure 12 : Workloads on different categories of foundryman in the 5 technical situations studied. For each foundryman, the workload is broken down as a function of 5 work phases.

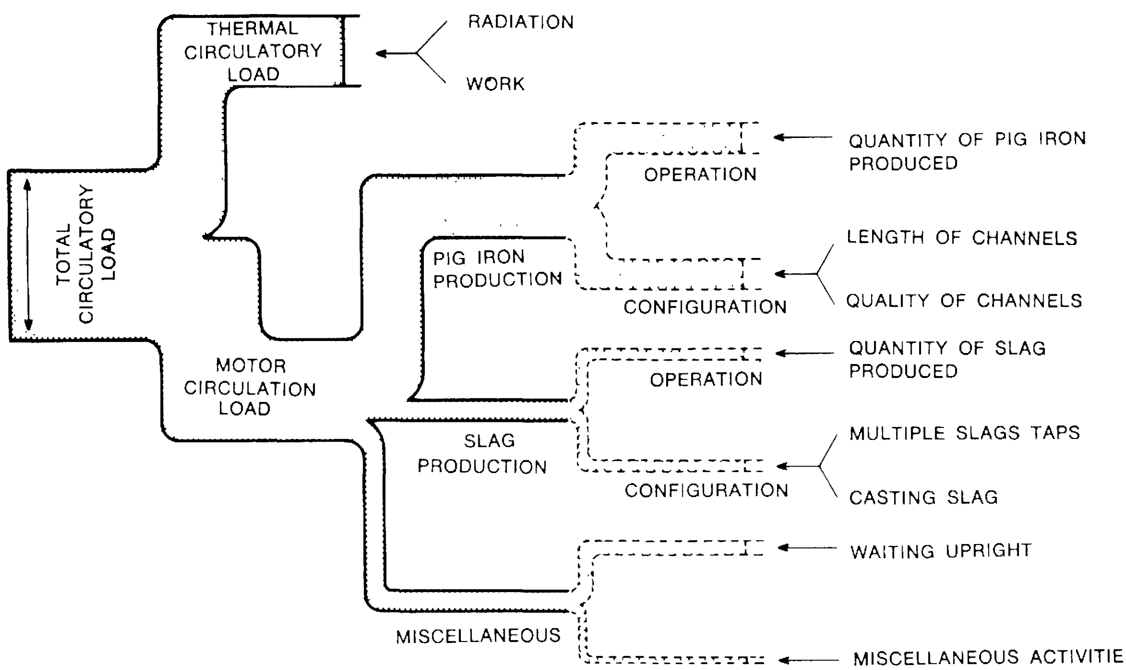

Figure 13 : Block diagram of the breakdown of total circulatory load into its different components. The thickness of the branches of this diagram is proportional to the importance of the factors shown in the figure.

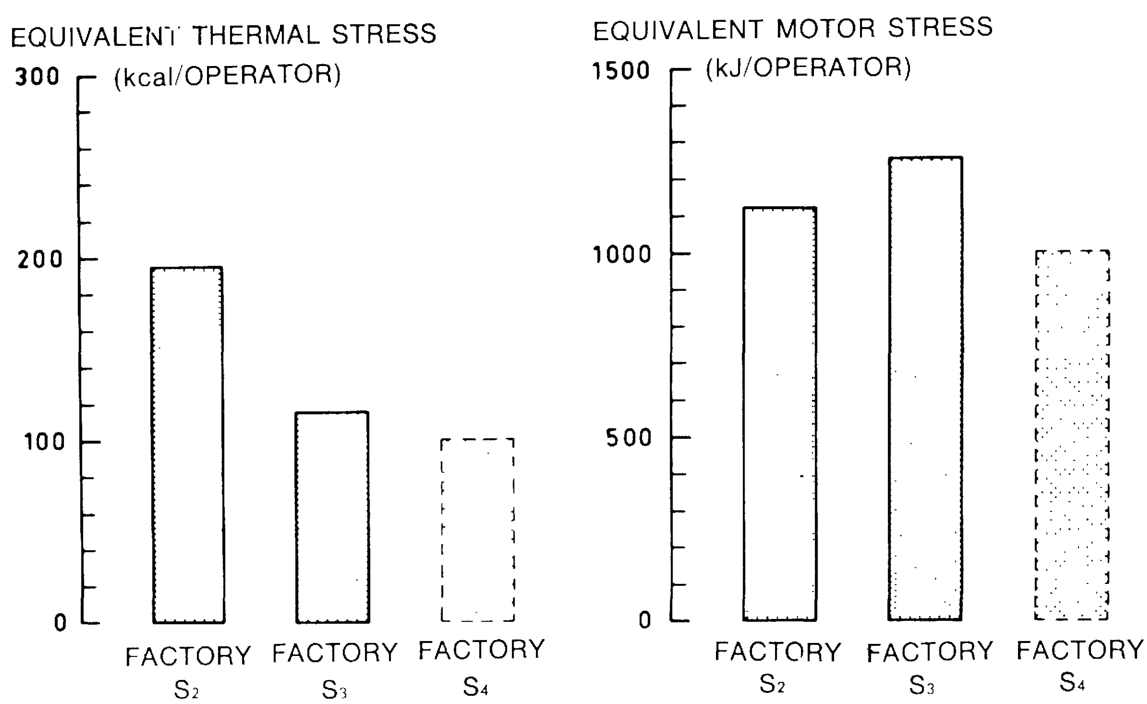

Figure 14 : Equivalent thermal stress and equivalent motor stress observed after modifying the casting platform of blast furnace S2. Situations S3 and S4 are derived from situation S2.