

LANCE CURRENTS IN B.O.S. PROCESSING*

by

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November, 1981

* Work supported by B.H.P. Central Research Laboratories:
Company Confidential.

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ABSTRACT

In this report, investigations are carried out as to the nature of B.O.S. lance electrical current measurements, possible lance current pathways in the vessel/hood area, and the source of these currents whether in the flame, oxygen jet, slag or melt. The report outlines the various possibilities for the current pathways and suggests experiments that would be helpful in giving more information on these and on other aspects of the electrical phenomena within the B.O.S. Calculation details, background theory and references are given in Appendices (not yet complete).

1. INTRODUCTION

In the B.O.S. process, electrical currents flow between the oxygen lance and earth via high conductivity pathways internal to the B.O.S. The sign, fluctuations and relative magnitudes of the lance currents appear to contain information about what is happening inside the B.O.S. vessel. This information may be of use to dynamically control heats, by adjusting lance height and oxygen flow rate so as to achieve the desired objectives in terms of yield, final temperature and final steel composition.

The monitoring of lance voltages (emfs) was first suggested in [1-3] and independently studied in [4]. A statistical model for the lance signals is developed in [5]. However, to date there has been no model proposed whereby reasonably simulation studies can be carried out, so as to optimize control strategies. Such a model cannot be developed until it is understood precisely how the lance currents are generated and the pathways through which they flow.

In this report, various alternatives are investigated for the origin of the lance currents and interpretations are made based on measurements to date. Experiments are proposed which could help further define the nature and source of the signals.

2. THE LANCE CURRENT MEASUREMENT

Electrical currents flowing from the oxygen lance of a B.O.S. vessel to earth via an external resistor R_L can be measured. In one 250 tonne vessel for example, currents up to 100 amps can flow from lance to earth via a $2.5\text{m}\Omega$ resistor and up to 20 amps in the reverse direction.

The B.O.S. electric energy source can be viewed as in Fig. 1.1 in terms of a voltage V_0 in series with an internal resistance R_0 . The values of R_0 and V_0 , as functions of time, can be inferred by measuring the voltage V_L across R_L for different values of R_L^* . Applying an external voltage source in series with R_L may also be useful in extracting information from the electrical energy source. Of course, V_0 and R_0 may depend at any time instant on the current flow and thus on R_L , but it is reasonably assumed that the values of V_0 and R_0 are influenced primarily by the processes in the vessel and hood.

With the lance clamp insulated, and monitoring the lance voltage via a connection at the top of the lance, gives an indication of V_0 . Actually in practice there is a $220\text{m}\Omega$ path to ground via the oxygen supply to the lance. The value of $R_L = 200\text{m}\Omega$ appears high relative to R_0 , at least for much of the time during the heat. There does not seem much point in further insulating the lance since the $200\text{m}\Omega$ effectively obscures any high resistance (low energy) sources supplying the lance. Such sources may contain useful information if they can be studied in isolation from the higher energy sources, but to attempt such a study in the first instance seems unwarranted. Nevertheless, at some stage it may be of interest to insulate the oxygen supply from earth to assess the situation more precisely.

* With a fixed R_L , the value of $V_L = V_0 R_L / (R_L + R_0)$ which does not allow solution for V_0 and R_0 independently.

To study R_0 , which is a measure of the resistivity of the lance current pathways, the observations in [3] when switching in a $2.5\text{m}\Omega$ load via the lance clamp are relevant. The lance voltage drops by a factor of 2 or 3 in the high decarbonization part of the heat, and by 10 in the early and latter parts. Simple calculations give R_0 (minimum values) from $1.5\text{m}\Omega$ to $25\text{m}\Omega$ for the positive lance currents and much less than $1\text{m}\Omega$ for negative lance currents.

A reasonable assumption is that R_0 is within a factor of 10 of its minimum value for most of the time. If the pathways exist exclusively in the flame, for example, then flame conductivities ranging over 10^2 to 1 could be expected for much of the time.

Since V_0 and R_0 cannot be measured simultaneously, a load resistor of $2.5\text{m}\Omega$ has been chosen to measure lance current so as to reflect variations in R_0 over the wide ranges which appear possible.

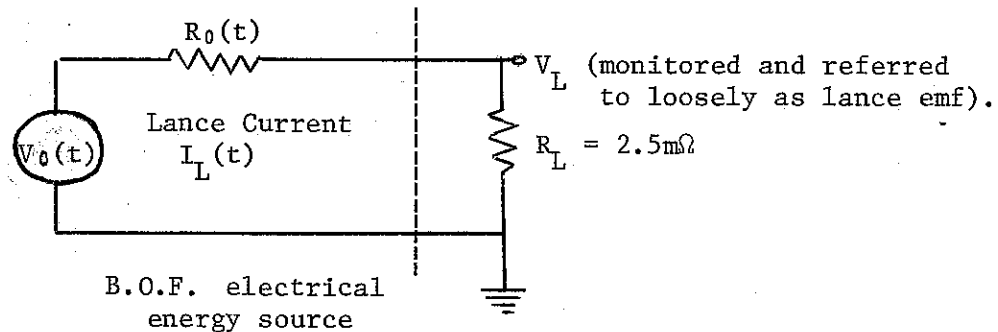


Figure 1.1: The Equivalent Circuit

With a higher load resistance, e.g. $220\text{m}\Omega$, fluctuations of R_0 from $1\text{m}\Omega$ to $25\text{m}\Omega$ will have a relatively insignificant effect on V_L .

With a lower load resistance, e.g. $1\text{m}\Omega$, other effects attenuate the signal to a series of pulses not containing much information.

With a value $10\text{m}\Omega$, there is less discrimination on fluctuations in R_0 in the range of $10\text{m}\Omega$.

Experiments:

1. Switch between load resistors to more precisely identify fluctuations in R_0 , and to assess V_0 . Solenoids (as in car ignition systems) may be suitable.
2. Include a DC (or AC) voltage in series with the load. A start maybe to try a 6 volt car battery to swamp out fluctuation in V_0 and to assess effect of lance current on R_0 , and V_0 .
3. Work towards an uninterrupted measurement of V_L - perhaps via an attachment to the oxygen supply hose or a separate clamp.
4. Insulate load resistor R_L to reduce effects of temperature change throughout the heat.
5. Assess the anomolous measurements which indicate that in applying the $2.5\text{m}\Omega$ load, the lance current can change sign from positive to negative - perhaps by virtue of lance movement changes.
6. Switching in a load resistor $R_L = 1\text{m}\Omega$ has been tried and attenuates the positive signals to short spikes. This maybe due to the lance current or voltage influencing V_0 and or R_0 . What happens for negative lance currents, or for skewless signals wandering across the zero current line? This could be investigated further with benefit to our understanding of the phenomena.
7. When relining a vessel, there can be inserted a "short" between the melt and earth which would perhaps increase lance currents by virtue of reducing internal resistances between lance and earth. (see also next section).

3. LANCE CURRENT PATHWAYS

The low values of the internal impedance R_0 are significant in determining where the lance current signals originate. There are of course many voltage sources present due to contact potentials, thermal and concentration gradients, movement of charged particles, oxidation potentials etc, but not all these have low internal resistances in the associated current pathways.

Broadly speaking there are four or more possible current pathways between lance and earth, internal to the process. One or a combination may be present

- (i) lance-flame-hood-earth
- (ii) via vessel lining and shell
- (iii) via vessel lining surface, vessel rim and shell
- (iv) direct lance melt contact
- (v) via slag to earth

(1) Lance-flame-hood-earth

In order to achieve flame pathway resistivities in the hood area down to milliohms or fractions of milliohms, the electron concentration levels in the flames must be high relative to those measured in laboratory flames, including magneto-hydro-dynamic (MHD) combustion products. Also space charge voltage drops in the vicinity of the lance and earth (sheaths) must be small compared to those experienced on needle fine Langmuir probes. Even so, such pathways are not excluded as far as the author can assess at this stage.

Specific evidence for a purely flame pathway are as follows:

- (a) Ignition causes lance current pulses, although not of high energy.
- (b) A wall electrode gives signals which may be from the flame, although they may only measure slag splattered lining surface voltages.
- (c) For negative lance currents, there is evidence that the only pathways to earth are via the oxygen jet or flame, see also (f).
- (d) Quenching the flame as in a flux drop, reduces the lance current to zero.
- (e) In a flux drop where quenching does not occur, the lance current in the positive regime is boosted, perhaps by the addition of alkali seeding for flame ionization.
- (f) In a reblow (soft) and before the slag has time to foam up, there is sometimes a negative lance current for $\frac{1}{2}$ minute.
- (g) Blowback in the hood seems to short out negative signals.

Experiments:

1. Langmuir probe type experiments could be performed in the hood area to study flame ionization levels, conductivities, etc.
2. Vortex shedding on the hood can be studied via movie film in relation to the lance current and lance wobble as suggested under the heading "Vortex Shedding".
3. In reblows with slag removed, it would be significant to document the lance currents - possibly confirming that without metal or slag lance contact, significant currents flow. It is postulated that these will be negative, since the flame would not emerge from a slag surface.
4. Insulating the lance body in various subsections could be of great value in assessing flame or slag pathways. Perhaps a

ceramic pipe sheath could be used. Maybe (tongue in check)

we could tile on some space shuttle tiles.

(ii) Via vessel lining and shell

The vessel shell having refractory penetrated with graphite save for the safety lining, may be conducting at high temperatures. Its conductivity, hot or cold, is not known by this author.

As a hole in the lining develops near the melt/slag interface to within 20cm of the steel shell, it has been observed that lance currents increase, suggesting that currents flow via the melt/slag through lining to earth. Such holes have been observed only towards the end of a campaign when positive rather than negative lance currents occur. Regunning the lining with MgO reduces lance currents by what appears to be simply a scale factor of up to five- from as much as 250mV across $2.5\text{m}\Omega$ down to 50mV across $2.5\text{m}\Omega$.

The above observation suggests that unless there is some direct electro chemical contribution of the lining to the lance current as it is attacked, then the lining and thus melt/slag interface has much to do with positive lance currents. One is tempted to exclude the significance of a flame-hood path for positive lance currents from this observation alone.

Experiment:

1. In relining the furnace, wire an electrical (but not thermal) connection between melt and vessel shell. The lance currents should increase by perhaps a factor of five or more confirming the melt-lining-shell pathway. There may be an advantage in working with larger lance currents should it be possible to

ensure a melt-earth connection by a suitable design of the linkage. Of particular interest is the influence of the connection on negative lance currents so as to assess indirectly the possibility of a flame-hood pathway for these, and more directly the pathway via the lining.

2. In a relining of the furnace, there would be value in assessing conductivity of samples of the lining and the slag that is on the surface of the lining between rim and melt.
3. At a later stage it may be worth bringing out of the vessel a connection with the melt so as to examine the current/voltage characteristic for internal impedance assessment.

(iii) Via vessel lining surface vessel and shell

Slag samples taken from the lance clamp showed high conductivities (cold) due to high metalisation. It maybe that the vessel lining surface is a low resistivity path to earth.

Experiment:

1. Measurement of conductivity of slag lining the walls of the vessel could be carried out both cold and hot. Applying a voltage between melt and earth could be useful here.

(iv) Direct lance melt contact

It may be thought that with negative lance currents on harder blowing there is continued contact of the melt with the lance via streamers of the melt thrown up*. These are not assumed to be present with softer blowing. Thus one pathway for negative currents is lance-melt-earth. This is probably excluded by one observation.

A soft reblow on one occasion produced a negative lance current

* Such may explain the fact that $R_0 \ll 1 \text{ m}\Omega$ for I_L negative.

to earth. In a soft blow there is not the turbulence to send up streamers 2 meters to the lance through a collapsed slag.

(v) Via slag to earth

It is known that a probe into the slag at turn down gives 50-400mv positive contact potential, oxidation potential or thermal gradient voltage relative to earth (the melt is in contact with the lip of vessel which is earth). However the internal impedance of this for the test probes ($< 1 \text{ cm} \times 1 \text{ cm} \times 20 \text{ cm}$ in contact with slag) gives 1Ω . Is the lance - slag - earth pathway for a thermal emf feasible? The slag will be foamed and with prills, the oxygen lance will have a bigger contact area, but there will be a less certain path from slag to earth. Rather than calculate this, the following observation tells us the most probably answer.

A sudden cut in the oxygen supply while a positive lance current flows to earth, reduces this current instantaneously to "zero". This was repeated 4 or 5 times in one heat. It is assumed that the slag has frothed up to contact the lance*. A sudden collapse of this is not likely with an oxygen cut. If the slag is not frothed up to the lance, then of course the slag could not be a pathway for the electrical signal. We conclude that the electrical pathway is not lance - slag - earth, at least for the same source of voltage as in the slag dip experiment. It may form part of the pathway for a voltage produced by other effects such as a fuel cell effect.

Experiments:

1. Pathways to earth via the vessel rim, shell and trunion could be monitored by measuring current flows down the trunions.

* It should be checked that the lance is not unclamped at these O_2 cuts.

It is known that voltages at the trunion to a cabin earth are about 1m v , but it is not known what the voltage directly across the trunion is. These could be measured, although perhaps with difficulty.

2. [As in previous subsection]. It is suggested to look at lance currents during a reblow where the bulk of the slag is removed prior to the few minutes of reblow. A negative trace would confirm that slag need not be involved in the production of negative signals.

Conclusion on Lance Current Pathways

Until some of the above suggested experiments are carried out, it appears difficult to home in on a particular current pathway by theoretical speculation, or to eliminate any of them solely by a single observation. Perhaps all are involved to varying extents throughout the process.

4. SOURCE OF LANCE CURRENTS

We seek the source of the large lance currents that flow by means of low internal resistive pathways (R_0 less than $25\text{m}\Omega$). The pathways are assumed to have only intermitantly low resistance, thereby giving rise to fluctuating lance currents.

Possible lance current sources in flames are as follows:

(i) Thermal Diffusion Gradients (Thermal emf):

Thermocouples can give the appropriate level of voltage over a 1600°C temperature difference observed in the B.O.S. The fact that when the oxygen flow rate is cut to zero there is no significant lance current, suggests that the lance-slag-melt-rim-shell thermocouple of itself is of insignificance here. Thermal gradients in the combustion products to lance and earth via rim or hood are not excluded by this observation since the nature of the combustion products changes instantly with an oxygen cut. Thermocouples can give both negative and positive currents depending on the materials and temperatures. The key parameter is the Seebeck parameter. The most mobile charge carrier dissipates the heat energy constituting a current flow.

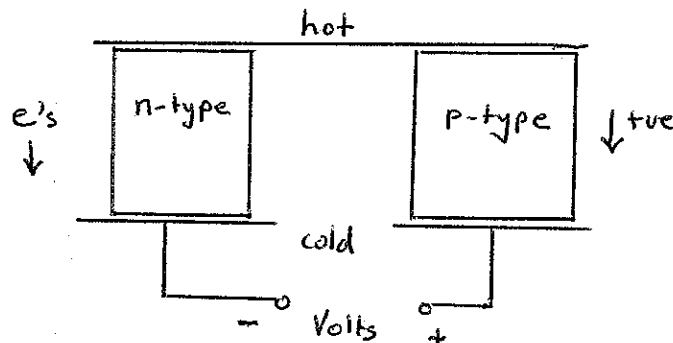


Figure 4.1

Thermal emf example

Here the slag could well be a p-type material with positive carriers Fe or Ca cations. The flame could be negative with electrons as carriers. It is hard at this stage to define low impedance pathways for the current flow if slag is involved.

(ii) Diffusion of higher mobility charges in a gradient of varying charge concentrations - assuming overall neutrality, e.g. in a plasma (flame) or electrolyte (slag). This is analogous to the flow of current in the base of a transistor. This mechanism may explain negative currents, since higher temperatures near the hood due to $O_2 + 2CO \rightarrow 2CO_2$ may give higher electron concentrations which would flow to the lance. It is not unreasonable that under other conditions there exists a charge gradient moving away from the lance giving an electron current flow and thus a positive lance voltage. Such does not require slag contact with the lance. Observations suggest that for a positive lance current, slag contact may be necessary, in which case this explanation for positive lance currents need not be explored further.

(iii) Movement of excess positive or negative charges between lance and earth, swept along by the movement of the gases. In a candle flame there are excess positivity charged carbon particles at the flame limits. One charge to each particle in the size range of 90-200 Angstroms ($1A = 10^{-10}$ microns). Perhaps the same exists here with Fe_2O_3 particles when negative currents flow and the flame is lean, making visible the lance at times. Such particles would be swept from lance area to hood (earth) area and constitute a negative current. A doubt for this mechanism is that the negative currents are as from a voltage source rather than a current source as appears would arise from this mechanism. ^m Fine studies do not cover the size range of particles suggested here, being limited to particles > .05 micron.

(iv) Fuel cell potentials as when there is an exchange of electrons at electrodes (lance, melt, hood) via chemical processes or ionization. Another name is oxidization potentials as when differing electrodes are employed in an electrolyte. With oxygen blown on ignited graphite there is a $+1\frac{1}{2}$ volt signal available on the oxygen lance. This is due to thermionic emission at the oxygen lance negatively charging the oxygen, which then carries the negative charges to the carbon/oxygen reaction where the electrons are taken in by the carbon electrode. The conductivity of the pathways is reduced by alkali ionization [6].

The relevance of this process depends on a low conductivity path from the melt to earth - not yet assessed.

(v) Calorelectric effects - as when high temperature electrons move from gas to hotter electrode against any charge barrier. This seems one possibility for the negative lance currents when the lance is surrounded by high temperature gases. It is not established what the free electron concentration is, however, or how much above the gas temperature is the electron temperature.

Possible lance current sources between the slag/melt/lining have not been studied closely at this stage. However two possibilities can be considered:

(i) As suggested in the Russian literature when the lance currents are positive, F_e^{2+} cations are in excess in the slag, with electrons in excess in the melt. When the slags are over oxidized, then O_2^- anions are in excess in the slag and the lance is negative. In this view, the slag is an electrolyte and the electrodes

are melt and lance, it being assumed that the melt is at earth potential. This view explains the fluctuations of the lance currents in terms of varying slag contact with the lance. It is hard to explain with this view the sudden collapse of the signal with the $2.5\text{m}\Omega$ load when the oxygen supply is cut accidentally, or negative signals when there appears to be no slag contact.

(ii) Oxidation potentials due to reactions at the melt and vicinity of lance.

Experiments:

1. It is believed that the pinning down of the current pathways as in the previous section is the key to identifying the electrical sources.
2. Skewless lance currents seem to wander across the zero current line as though it does not exist. It would be of interest to test the hypothesis that such signals are due to the sum of negative and positive like signals - perhaps from two separate phenomena in the one vessel. Adjusting the oxygen flowrate during such a trace may be of help here, or switching loads via the lance clamp as in experiments in [3].
3. It would be of value to cut oxygen supply in a negative lance current regime. Also to monitor lance "voltages" with $R_L = 220\text{m}\Omega$ when the oxygen supply is cut. Incidentally, omitting oxygen supply has been employed to allow prills of Fe to settle during a heat after a soft blow. This technique assists dephosphorization.

5. MISCELLANEOUS TOPICS

5.1 Ionization in the Flame [7]

Chemi-ionization is a key source of ionization in hydrocarbon flames, but is thought to be absent in carbon oxygen flames - thus explaining their relatively low ionization levels. However in the B.O.S. chemi-ionization may be involved.

Alkali thermal ionization is the usual source of ionization in C/O₂ flames at temperatures under 2500°K.

Iron Ionization - The Fe which boils off may be ionized in part due to thermal ionization. Its ionization potential is higher than for Na or K but its mass level is much greater.

Iron Oxide Ionization - It is thought that particles ionize in flames if approx 100A° in diameter, (maybe there is more Fe loss up the stack in some modes of B.O.S. operation than others. This can be examined).

Presence of Electrons - The higher mobility of electrons (factor of more than 500) means that their presence would constitute the bulk of any current flow. The low path conductivities suggest that electrons must be present if the flame is a current pathway. Langmuir (type) probe experiments could determine this.

Thermionic emission. This could well be the source of electrons. CaO has a low work function and is used in vacuum tubes to emit copiously at 700°C. Here CaO is in the slag. Fe itself could well be a source of thermionic emissions at the melt surface or in particles. At the lance, CuO on the nozzle linings could be source. Particles of Fe₂O₃ could be a significant source.

5.2 Slopping

Experiments:

1. When metal ejections occur during negative lance current regimes. raise lance to see if there is an instant response. One hypothesis is that when the lance is too low, the craters in the bath collapse or break through or penetrate to the bottom of the vessel and metal is ejected. This effect should instantly disappear if the lance is raised significantly. Other sustaining interactions with melt and slag may also be involved and render this ineffective.
2. In positive regimes when slopping, add more material (e.g. lime or whatever maybe appropriate) to test if the mechanical action of the "stones" falling through the slag foam collapses the foam significantly. The additions should be allowed within the static model a priori.
3. In positive regimes, when slopping, the melt may be lower than operators might think due to high slag Fe content (as FeO and prills). A small drop in the lance will not achieve a hard blowing condition which could break up the foam. A relatively drastic drop in the lance is suggested during slopping to achieve negative lance currents and a breaking up of the foam. This has happened once accidentally with success. It is not suggested to keep the lance at this lower level after the foam is broken up.
4. Preventing the lance from swinging wildly (at 16 revs./min) may reduce slopping. This could be of importance when adjusting the lance height.
5. A gradual lowering of the lance when the bath emulsion is forming with positive lance currents may prevent slopping. The idea is to keep lance height above the melt constant. Recall that up to 30%

of the iron may be in the emulsion at times in the form of oxides and prills, and thus the melt is gradually lowered as this emulsion forms.

6. Run with negative lance currents the whole heat by lowering the lance sufficiently. To reduce phosphorous, add iron oxides (ore) to the flux. It is believed from recent research that while hard blowing, the "only" reason to form slag emulsions is to reduce the phosphorous. If iron oxides are not produced in sufficient quantity with hard blowing, then they could be added.

5.3 Lance Swinging

The lance moves like a simple pendulum under perturbation forces within the vessel. Observations suggest that the lance moves a lot during slopping and yet very little during negative lance currents. Unclamping the lance can switch negative currents to positive ones as the lance moves. As the lance touches a limiting plate, there is a short to earth and the lance voltage goes to zero accordingly. On the recorder, due to the 5Hz freq. response of the recorder, the trace may not reach zero.

The period on one lance current trace was 16 shorts/minute giving $3\frac{3}{4}$ second period and $2\frac{2}{3}$ Hz. The $3\frac{3}{4}$ second period appears close to that of some of the larger pulses in the recorder trace, although the latter are frequency and amplitude modulated with apparently random signals.

Recall that a simple pendulum has a period 1 sec. at 24.8cm, 2 secs and 4×24.8 cm, 3 secs at 9×24.8 cm etc and $3\frac{3}{4}$ secs at 3.48 meters.

A swing of 6 inches at the lance clamp top is a 6" in 6' swing or $\frac{3}{4}$ meter in 9 meters causing the 2 meter oxygen jets to transverse within a radius of $1\frac{1}{2}$ meter or so varying in length by up to 10cm.

Experiments:

1. Monitor the swinging of the lance - its amplitude and frequency as a function of time. See if there is any correlation with the lance current trace, and slopping. Perhaps slag viscosity can be monitored via such measurements. One possibility for monitoring the swing is some guage on the lance clamp. An attachment which does not interfere with lance could be used. Displacement, oil pressure, or strain gauges are possibilities.
2. Organize to hold the lance more firmly when seeking to enter regimes with negative lance currents. At Port Kembla, the fixed lance is perhaps responsible for the greater occurrence of negative lance currents.
3. Stir the vessel via the mechanical manipulation of the lance at various frequencies and observe the response in the lance current. There could well be melt stirring modes or vortex shedding modes in the upper flame excited at their appropriate frequencies. Also, there may be an influence on the slopping behaviour at some frequencies. There may be observations to make when the lance is held firmly. It is known that stirring at ≈ 5 rpm up to 40% radius of vessel can achieve virtually the same beneficial results as bottom blowing in that stratification in temperature and composition in slag and melt may be reduced.

5.4 Vessel Tilting

In searching for controls for the process, one possibility is small low frequency tilting of the vessel. Of course any rapid movement would excite seiching modes, but very slow (say 3 tilts per minute of appropriate angle $5 \rightarrow 10^\circ$) may assist with bath

stirring and be easier to implement than lance stirring. Its effect on the lance currents would be of interest.

5.5 Vortex Shedding

For flames from nozzles there can be coherent turbulent structures within a few nozzle diameters from the rim of the nozzle. These are characterized by a frequency of occurrence, and puffs are referred to as vortex shedding. Frequency of vortex shedding can be calculated from exit gas velocity v , nozzle diameter d , and Strouhal number ($St = .7 \rightarrow .9$ for methane flames at Reynolds number 3000). Thus frequency f is given from $f = v \cdot St/d$.

For the B.O.S. vessel viewed as a nozzle, the vortex shedding freq. with $d = 3m$, $v = 10 \rightarrow 20m/sec$, $St = .9$ is $3 \rightarrow 6Hz$.

Of course the Strouhal number may be different for the B.O.S. flames. The hood and air entrainment may influence St , also.

The frequency and effects can be influenced by perturbations at the nozzle, such as by lance movement.

The Reynolds number has only a second order effect. For the B.O.S. it is calculated to be 160,000.

Maybe the intermittency influences the flame in the hood area via Poisson processes as studied in [5].

Experiments:

1. Pressure transducer in hood area - perhaps at the end of a pipe. Acoustic records could be filtered for frequencies less than 10Hz. These may be correlated with the lance current signals. Modulation on higher frequency components.
2. Use a movie camera to record flames at the vessel throat and at the hole in the hood where the lance enters. Synchronize

these with the lance current traces. Appropriate filters could be used.

3. Force an oscillation frequency in the lance via mechanical means to see if there is an influence on the vortex shedding modes as observed by movie or lance current. [See lance swinging].
4. A light cell above the lance hood hole could be used to detect when the flames thrust through this hole. This simple experiment may lead to some useful correlations with the lance current signal.

6. CONCLUSION

The report has opened up a number of areas for further investigation. Some of these areas can be tackled using data now available but not yet readily accessible to the author. Other experiments can perhaps be embarked on which do not influence production procedures significantly.

ACKNOWLEDGEMENT

The author wishes to acknowledge the enthusiasm on the project imparted by Neil Molloy from discussions, the experimental work devised for the author, and his patience with an electrical engineer working with concepts in chemistry and metallurgy.

The author wishes to thank John Mathieson for access and interpretation of the B.O.S. plant and control equipment, and the task force reports on the emf signal. Also, John Mathieson has clarified the areas for present and future research on the project. The author wishes to acknowledge the vital observations, insights and suggestions from Gary Kemlo which are woven into this report, and likewise for those of Ian Musgrave.

REFERENCES

- [1] S.P. Parinov, V.P. Loktionov and S.A. Dubrovskii, "Monitoring oxygen content in slag in controlling basic oxygen steel making", Investiya VUZ Chernaya Metallurgiya, Dec. 1978, (12), 144-148.
- [2] S.V. Kolpakov, V.P. Loktionov, S.V. Radilov, B.N. Kozheonikov, M.M. Kataev and A.M. Pozbivanov, "Author Certificate 502948 cl, S2155/30", Otkrytiya, Izobr, Prom. Obrax, L. Tov, Zneki, 1976, (6), 66.
- [3] C. Ya Zarvin et al., "EMF signal study of converter melting", Staleplavil'noe Proizvodstvo, 1975, pp. 84-90.
- [4] K.G. Kemlo, "Dynamic control of the B.O.F. using an electrical signal generated from the reactions occurring during the refining operation", B.H.P. Report PQC 16, Dec. 1978.
- [5] R. Cowan, "The Siromath/BHP Stochastic Model of the B.O.S. Furnace", Report to B.H.P., Aug. 1981
- [6] S.L. Loo and G.M. Colver, "Calorelectric effect in graphite - oxygen flame, Twelve Symposium (International) on Combustion, Poitiers France, July 1968, pp. 3-7.
- [7] J. Lawton and F. Weinberg, "Extended Aspects of Combustion", Oxford 1969.

APPENDIX: - SUMMARY OF EXPERIMENTS THAT CAN BE PERFORMED IN THE SHORT TERM.

A. Off-line experiments

- (i) Slag on vessel lining, resistivity
- (ii) Trunion resistance
- (iii) Slag dip current flows
- (iv) Subtract lance and melt voltages on bottom electrode data
- (v) Melt lining current path in relining furnace.

B. On-line experiments

- (i) Sudden reduction of oxygen
- (ii) Tilt vessel
- (iii) Investigate skewless traces with oxygen and lance changes
- (iv) Eliminate slopping in negative by raising lance
- (v) Eliminate slopping in positive by temporarily lowering lance
- (vi) Eliminate slopping by additions
- (v) Slagless reblow to get negative signals
- (vi) Additions of silica
- (viii) Eliminate slopping by going to negative lance currents and adding FeO to reduce P possibly cutting O_2 supply at times.

C. Modifications to sensing equipment etc.

- (i) Add car (truck) solenoid in series with $2.5m\Omega$.
- (ii) Monitor lance/hood hole flame with light cell.
- (iii) Monitor lance movement.
- (iv) Clamp lance tighter to eliminate slopping in Regime 1.
- (v) Gradual lowering of lance when in Regime 1.