UNIDIRECTIONAL ANALYSIS OF THE CONTINUOUS CASTING PROCESS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The continuous casting process has been known for some time, and practiced extensively in the non-ferrous metals industries. Its application in steelmaking has been proposed for a decade or more, but has only recently been put into commercial practice.(1,2) Considerable work remains to be done regarding modifications to the process and development of techniques for accomodating other shapes, sizes, and compositions of steel. With the specific purpose of simulating the process, a simplified approach to heat transfer during the continuous casting of a steel slab is proposed. The following analysis is based on unidirectional heat transfer, i.e., a one-directional analysis of heat flow during continuous casting.

THE CONTINUOUS CASTING PROCESS

A generalized sketch of the continuous casting process is presented in Figure 1. The process consists of two distinct heat transfer stages;

1. A water-cooled copper mold which oscillates to maintain its separation from the continuously downwardly moving slab.
2. A high-velocity water spray which is located immediately below the mold to promote rapid heat transfer from the surface of the hot slab.

Two critical aspects of the process exist which are related to these heat transfer units. First, the extent of solidification, i. e., the thickness of frozen skin, for the slab as it emerges from the water-

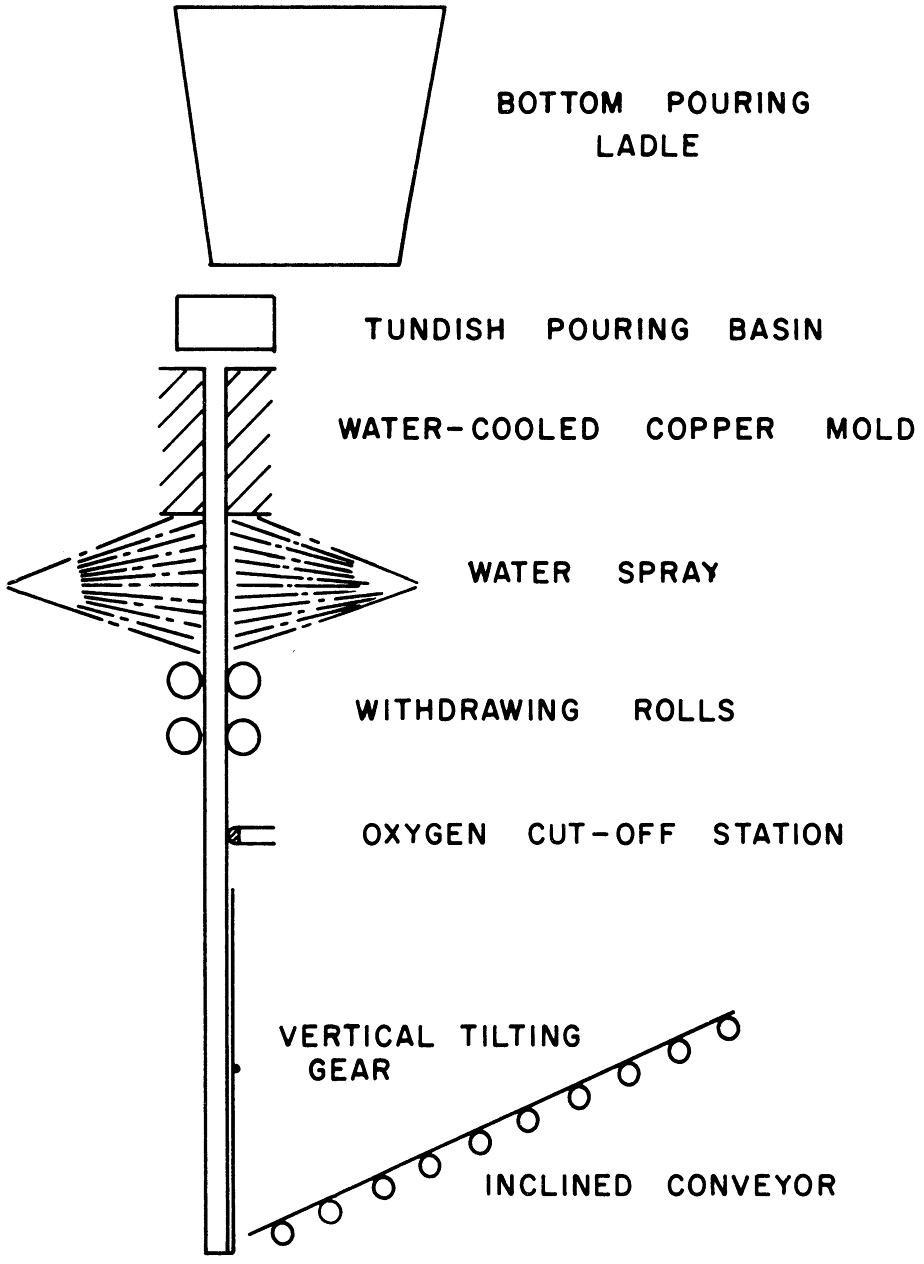


Figure 1. Schematic Diagram of Continuous Casting Process.

cooled copper mold must be great enough to support the head of liquid metal extending from the bottom of the mold up to the liquid metal surface. Secondly, the thickness of the solidified layer of metal leaving the water spray zone should be such that the solidification process is nearly complete, i.e., the liquid metal well which exists down through the center of the slab should not extend far below the water spray, such that the slab is completely solidified when it reaches the cutoff or bending station of the casting strand.

HEAT TRANSFER ANALYSIS

A. Copper Mold

Heat transfer in the copper mold can be analyzed on the basis of assumed heat transfer coefficients at each of the physical interfaces, and on thermal conduction both through the slab as its solidified thickness builds up, and through the wall of the copper mold. This path for heat transfer has been chosen, neglecting any heat transfer between liquid and solid steel within the slab. The rate of energy transfer from the liquid-solid interface to the water stream at any point along the mold, assuming steady state conditions, is given by Equation 1.

$$q = \frac{[(KS/X) * (TF-TW)]}{[1 + (KS/X) * (1/HMS + XM/KM + 1/HWM)]} \qquad (1)$$

where

q = the rate of heat transfer in Btu/hr
KS = thermal conductivity of solid steel in Btu/ft-hr-°F
X = thickness of the frozen layer in ft
TF = liquidus temperature of the steel in °F
TW = average temperature of the water flowing in the mold

HMS = heat transfer coefficient between the mold and the slab in Btu/hr-°F
XM = mold thickness in feet
KM = thermal conductivity of the mold material
HWM = heat transfer coefficient between the cooling water and the mold in Btu/hr-°F

Assuming steady-state heat transfer, the temperatures at each interface can be computed from thermal resistances and are given by the expressions:

$$TWM = q/HWM + TW \tag{2}$$

$$TMS = q * (XM/KM) + TWM \tag{3}$$

$$TSM = q/HMS + TMS \tag{4}$$

where

TWM = temperature of the mold on the water side in °F

TMS = temperature of the mold on the slab side in °F

TSM = temperature of the slab on the mold side in °F

The slab moves downwardly through the mold. By considering each discrete point along the vertical dimension of the mold as being a point where unidirectional steady-state heat transfer takes place, the heat extracted can be equated to the solidification of a given amount of steel. As solidification progresses, the heat extracted is equal to that to:

a. Remove the liquid super-heat, i.e., cool the steel from the pouring temperature to the liquidus temperature.

b. Remove the heat of fusion, assuming that this heat is extracted at a specific temperature.

c. Remove the heat from the already frozen steel in order to provide a linear temperature gradient through the slab.

In the present analysis a specific thickness of metal to be frozen per iteration was chosen, and the heat which must be removed to accomplish this can be computed from Equation (5);

$$\begin{aligned} \mathrm{QREQD} \; = \; & (\mathrm{TS}-\mathrm{TF}) * (\mathrm{CPL}) * (\mathrm{DX}) * (\mathrm{RHO}) + (\mathrm{HF}) * (\mathrm{DX}) * (\mathrm{RHO}) \\ & + ((\mathrm{TF} + \mathrm{TSM})/2) * (\mathrm{X}) * (\mathrm{CPS}) * (\mathrm{RHO}) + (\mathrm{TF})*(\mathrm{DX})*(\mathrm{CPS})*(\mathrm{RHO}) \\ & - ((\mathrm{TF} + \mathrm{TSM})/2) * (\mathrm{X} + \mathrm{DX}) * (\mathrm{CPS}) * (\mathrm{RHO}) \qquad (5) \end{aligned}$$

where

QREQD = heat in Btu required to freeze a steel increment of thickness DX in ft.

CPS = specific heat of the solid steel in Btu/lb-°F

RHO = density of solid steel in lb/ft^3

TS = temperature of the liquid steel in the well in °F

HF = heat of fusion of the steel in Btu/lb

The time required to remove the quantity of heat computed in Equation (5) is determined by the rate of heat transfer q under the physical conditions assumed to exist at any point along the vertical surface of the mold. The time required to remove this quantity of heat is given by the relationship;

$$t = \mathrm{QREQD}/q \qquad (6)$$

where

t = time in hours to freeze a increment of thickness DX.

The vertical movement of the slab can then be computed from the expression:

$$\mathrm{DIST} = (t) * (\mathrm{VEL})/(60) \qquad (7)$$

where

DIST = vertical distance in feet which the slab moves downward during the freezing on the layer of thickness DX

VEL = average downward velocity of the slab in ft/min.

In actual operating practice, the mold is usually given a vertical oscillating movement in order to prevent sticking of the slab to the mold walls. This movement has been ignored in the present analysis, assuming that its effect is of secondary importance. Also, an average heat transfer coefficient between mold and slab has been assumed.

B. The Water Spray

Heat transfer in the spray section of the strand can be computed in a manner parallel to that employed for calculating heat transfer in the copper mold. A heat transfer coefficient between the water spray and the slab is assumed. This surface resistance to heat transfer is added to that related to thermal conductivity in the solid portion of the slab, thus permitting a calculation of the rate of heat transfer q by the relationship

$$q = \frac{[(KS/X) * (TF-TW)]}{[1 + (KS/X) * (1/HSPS)]} \qquad (8)$$

where

HSPS = heat transfer coefficient between the water spray and the slab surface in Btu/hr-°F

and in a manner parallel to Equations (2), (3), and (4), the surface temperature of the slab can be estimated to be:

$$TSSP = (q/HSPS) + TW \qquad (9)$$

The heat which must be removed in order to effect the freezing of a layer of thickness DX during passage through the water spray can be calculated by considering the same heat terms as in the case of the copper mold. The heat which must be removed by the spray is:

$$
\begin{aligned}
\mathrm{QREQD} &= (\mathrm{TS}-\mathrm{TF}) * (\mathrm{CPL}) * (\mathrm{DX}) * \mathrm{RHO} \\
&+ (\mathrm{HF}) * (\mathrm{DX}) * (\mathrm{RHO}) \\
&+ ((\mathrm{TF}+\mathrm{TSSP})/2)*(\mathrm{X})*(\mathrm{CPS})*(\mathrm{RHO})+(\mathrm{TF})*(\mathrm{DX})*(\mathrm{CPS})*(\mathrm{RHO}) \\
&- ((\mathrm{TF}+\mathrm{TSSP})/2)*(\mathrm{X}+\mathrm{DX})*(\mathrm{CPS})*(\mathrm{RHO})
\end{aligned}
\tag{10}
$$

Equations (6) and (7) can then be employed to compute the vertical movement of the slab during the time period required to freeze an increment of thickness DX .

COMPUTER PROGRAM

Employing an iterative procedure in which the transfer at each successive point along the mold surface is computed based on the heat flow at the previously computed point, the thickness of shell as a function of position in the mold and spray system was estimated. The flow diagram for this iterative procedure is presented in Figure 2, and the computer program itself presented in Figure 3.

A summary of the input data used in the calculation is presented in Table I. The computer output is presented in Table II.

DISCUSSION OF RESULTS

The results of the computer calculation employing the data presented in Table I are shown graphically in Figure 4. The estimated thickness at the exit of the copper mold is approximately 1.55 inches and

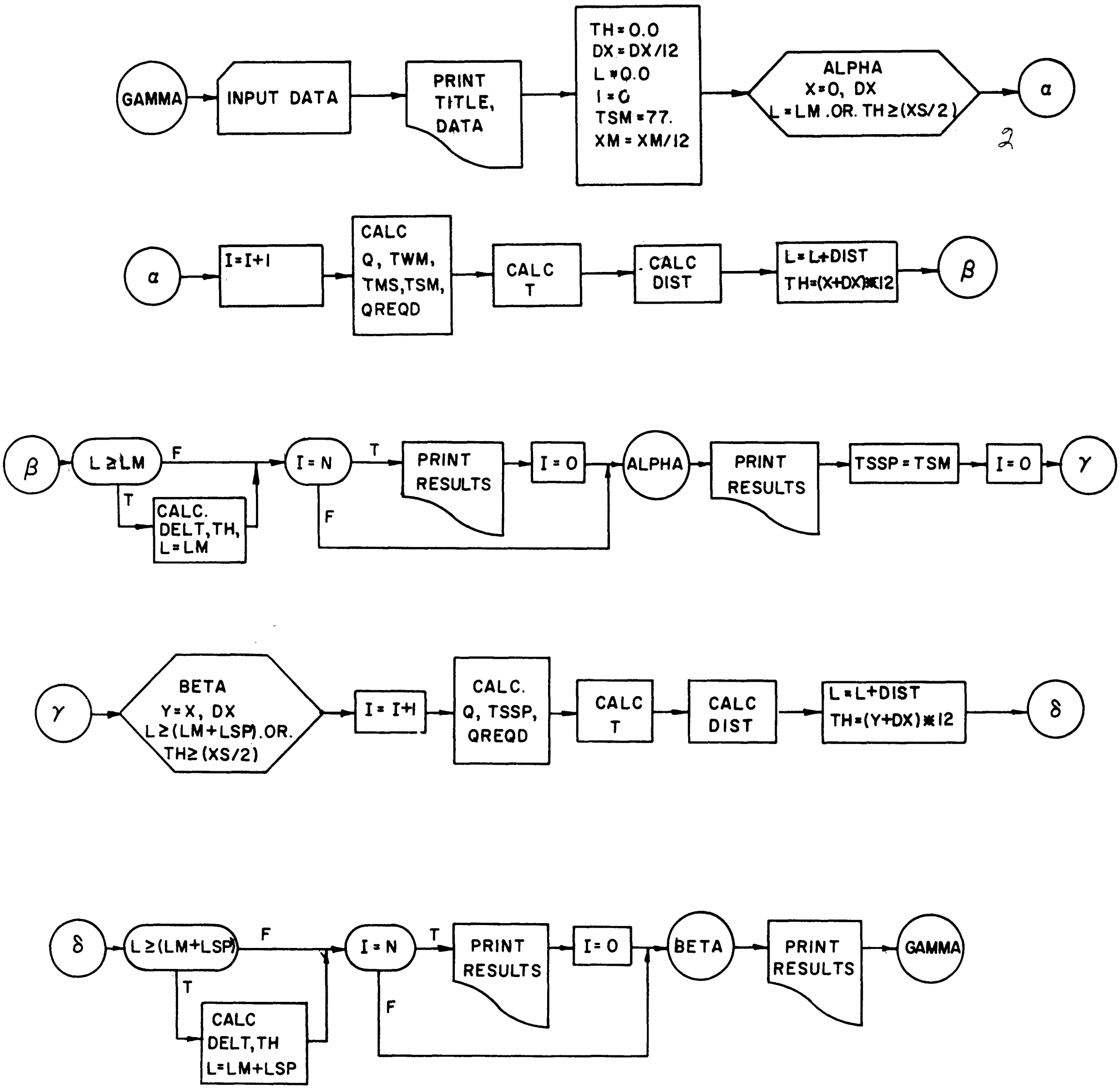
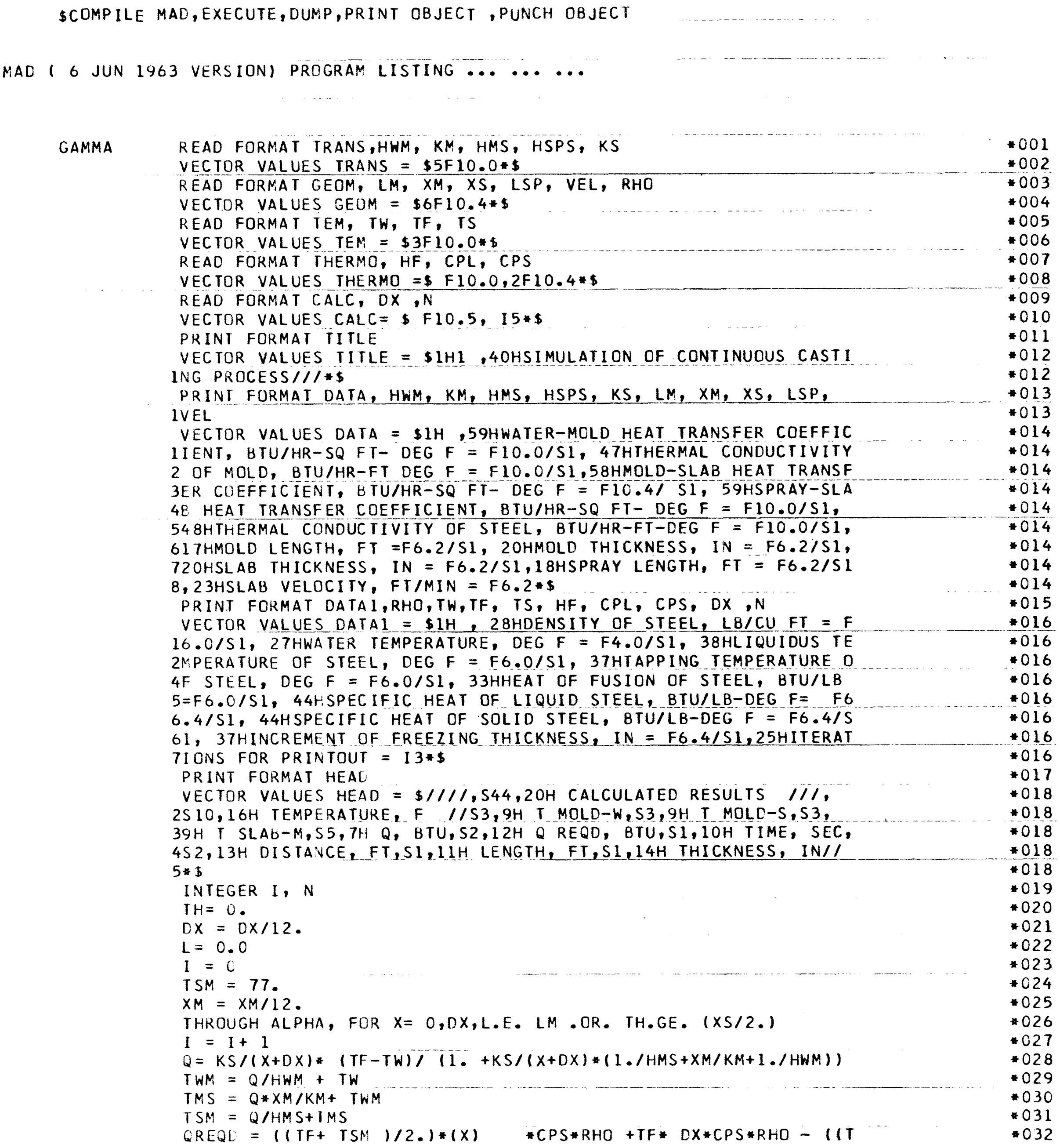


Figure 2. Flow Diagram for Computer Program.



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      $COMPILE MAD,EXECUTE,DUMP,PRINT OBJECT ,PUNCH OBJECT

MAD ( 6 JUN 1963 VERSION) PROGRAM LISTING ... ... ...

      GAMMA       READ FORMAT TRANS,HWM, KM, HMS, HSPS, KS                                        *001
                  VECTOR VALUES TRANS = $5F10.0*$                                                 *002
                  READ FORMAT GEOM, LM, XM, XS, LSP, VEL, RHO                                     *003
                  VECTOR VALUES GEOM = $6F10.4*$                                                  *004
                  READ FORMAT TEM, TW, TF, TS                                                     *005
                  VECTOR VALUES TEM = $3F10.0*$                                                   *006
                  READ FORMAT THERMO, HF, CPL, CPS                                                *007
                  VECTOR VALUES THERMO =$ F10.0,2F10.4*$                                          *008
                  READ FORMAT CALC, DX ,N                                                         *009
                  VECTOR VALUES CALC= $ F10.5, I5*$                                               *010
                  PRINT FORMAT TITLE                                                              *011
                  VECTOR VALUES TITLE = $1H1 ,40HSIMULATION OF CONTINUOUS CASTI                   *012
                 1NG PROCESS///*$                                                                 *012
                  PRINT FORMAT DATA, HWM, KM, HMS, HSPS, KS, LM, XM, XS, LSP,                     *013
                 1VEL                                                                             *013
                  VECTOR VALUES DATA = $1H ,59HWATER-MOLD HEAT TRANSFER COEFFIC                   *014
                 1IENT, BTU/HR-SQ FT- DEG F = F10.0/S1, 47HTHERMAL CONDUCTIVITY                   *014
                 2 OF MOLD, BTU/HR-FT DEG F = F10.0/S1,58HMOLD-SLAB HEAT TRANSF                   *014
                 3ER COEFFICIENT, BTU/HR-SQ FT- DEG F = F10.4/ S1, 59HSPRAY-SLA                   *014
                 4B HEAT TRANSFER COEFFICIENT, BTU/HR-SQ FT- DEG F = F10.0/S1,                    *014
                 548HTHERMAL CONDUCTIVITY OF STEEL, BTU/HR-FT-DEG F = F10.0/S1,                   *014
                 617HMOLD LENGTH, FT =F6.2/S1, 20HMOLD THICKNESS, IN = F6.2/S1,                   *014
                 720HSLAB THICKNESS, IN = F6.2/S1,18HSPRAY LENGTH, FT = F6.2/S1                   *014
                 8,23HSLAB VELOCITY, FT/MIN = F6.2*$                                              *014
                  PRINT FORMAT DATA1,RHO,TW,TF, TS, HF, CPL, CPS, DX ,N                           *015
                  VECTOR VALUES DATA1 = $1H , 28HDENSITY OF STEEL, LB/CU FT = F                   *016
                 16.0/S1, 27HWATER TEMPERATURE, DEG F = F4.0/S1, 38HLIQUIDUS TE                   *016
                 2MPERATURE OF STEEL, DEG F = F6.0/S1, 37HTAPPING TEMPERATURE O                   *016
                 4F STEEL, DEG F = F6.0/S1, 33HHEAT OF FUSION OF STEEL, BTU/LB                    *016
                 5=F6.0/S1, 44HSPECIFIC HEAT OF LIQUID STEEL, BTU/LB-DEG F=  F6                   *016
                 6.4/S1, 44HSPECIFIC HEAT OF SOLID STEEL, BTU/LB-DEG F = F6.4/S                   *016
                 61, 37HINCREMENT OF FREEZING THICKNESS, IN = F6.4/S1,25HITERAT                    *016
                 7IONS FOR PRINTOUT = I3*$                                                        *016
                  PRINT FORMAT HEAD                                                               *017
                  VECTOR VALUES HEAD = $////,S44,20H CALCULATED RESULTS  ///,                     *018
                 2S10,16H TEMPERATURE, F  //S3,9H T MOLD-W,S3,9H T MOLD-S,S3,                     *018
                 39H T SLAB-M,S5,7H Q, BTU,S2,12H Q REQD, BTU,S1,10H TIME, SEC,                   *018
                 4S2,13H DISTANCE, FT,S1,11H LENGTH, FT,S1,14H THICKNESS, IN//                    *018
                 5*$                                                                              *018
                  INTEGER I, N                                                                    *019
                  TH= 0.                                                                          *020
                  DX = DX/12.                                                                     *021
                  L= 0.0                                                                          *022
                  I = 0                                                                           *023
                  TSM = 77.                                                                       *024
                  XM = XM/12.                                                                     *025
                  THROUGH ALPHA, FOR X= 0,DX,L.E. LM .OR. TH.GE. (XS/2.)                          *026
                  I = I+ 1                                                                        *027
                  Q= KS/(X+DX)* (TF-TW)/ (1. +KS/(X+DX)*(1./HMS+XM/KM+1./HWM))                    *028
                  TWM = Q/HWM + TW                                                                *029
                  TMS = Q*XM/KM+ TWM                                                              *030
                  TSM = Q/HMS+TMS                                                                 *031
                  QREQD = ((TF+ TSM )/2.)*(X)    *CPS*RHO +TF* DX*CPS*RHO - ((T                   *032
```

Figure 3. Computer Program.

```
          1F+TSM)/2.)* (X+DX) *CPS*RHO +(TS-TF)* CPL*DX*RHO+ HF*RHO*DX                      *032
           T = (QREQD/Q)*3600.                                                              *033
           DIST = (T*VEL)/60.                                                               *034
           L = L + DIST                                                                     *035
           TH = (X+DX)*12.                                                                  *036
           WHENEVER L .GE. LM                                                               *037
           DELT = (LM -L)* DX/DIST                                                          *038
           X = X+DX+DELT                                                                    *039
           TH = X*12.                                                                       *040
           L = LM                                                                           *041
           OTHERWISE                                                                        *042
           CONTINUE                                                                         *043
           END OF CONDITIONAL                                                               *044
           WHENEVER I.E. N                                                                  *045
           PRINT FORMAT OUT1, TWM,TMS, TSM, Q, QREQD, T, DIST, L,TH                         *046
           I = 0                                                                            *047
           OTHERWISE                                                                        *048
           TRANSFER TO ALPHA                                                                *049
           END OF CONDITIONAL                                                               *050
ALPHA      CONTINUE                                                                         *051
           PRINT FORMAT OUT1, TWM,TMS, TSM, Q, QREQD, T, DIST, L,TH                         *052
           VECTOR VALUES OUT1= $1H , 3F12.4, F12.0, F12.2, 4F12.5*$                         *053
           TSSP = TSM                                                                       *054
           I = 0                                                                            *055
           THROUGH BETA, FOR Y=X     , DX, L.GE. (LM+LSP) .OR. TH.GE. (XS                   *056
          2/2.)                                                                             *056
           I = I + 1                                                                        *057
           Q= KS/(Y+DX)* (TF-TW)/(1.+ KS/(Y+DX)*(1./HSPS))                                  *058
           TSSP = Q/HSPS + TW                                                               *059
           QREQD = ((TF+TSSP )/2.)*Y*CPS*RHO+TF*DX*CPS*RHO-((TF+TSSP)/2.                    *060
          2)*(Y+DX)*CPS*RHO+ (TS-TF)*CPL*DX*RHO+HF*DX*RHO                                   *060
           T = (QREQD/Q)*3600.                                                              *061
           DIST = (T*VEL)/60.                                                               *062
           L= L+ DIST                                                                       *063
           TH = (Y+DX)*12.                                                                  *064
           WHENEVER L .GE. (LM+LSP)                                                         *065
           DELT = ((LM+LSP)-L)*DX/DIST                                                      *066
           Y = Y+DX+DELT                                                                    *067
           TH = Y*12.                                                                       *068
           L = LM + LSP                                                                     *069
           OTHERWISE                                                                        *070
           CONTINUE                                                                         *071
           END OF CONDITIONAL                                                               *072
           WHENEVER I.E. N                                                                  *073
           PRINT FORMAT OUT2, TSSP, Q, QREQD, T, DIST, L, TH                                *074
           I = 0                                                                            *075
           OTHERWISE                                                                        *076
           TRANSFER TO BETA                                                                 *077
           END OF CONDITIONAL                                                               *078
BETA       CONTINUE                                                                         *079
           PRINT FORMAT OUT2, TSSP, Q, QREQD, T, DIST, L, TH                                *080
           VECTOR VALUES OUT2 = $1H , F36.4, F12.0, F12.2, 4F12.5*$                         *081
           TRANSFER TO GAMMA                                                                *082
           END OF PROGRAM                                                                   *083
```

Figure 3. (Continued)

TABLE I

INPUT DATA FOR COMPUTER CALCULATION

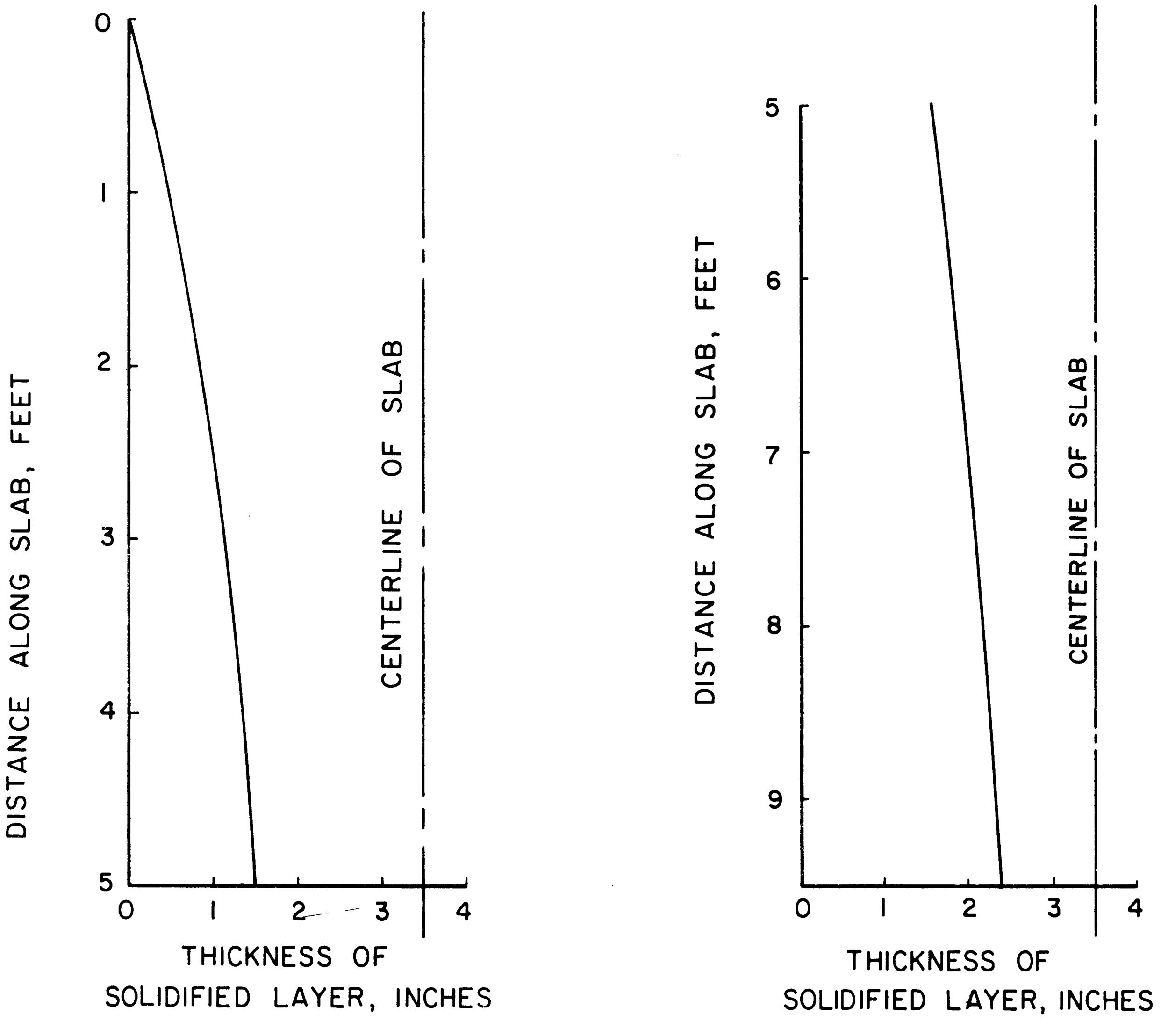
```
SIMULATION OF CONTINUOUS CASTING PROCESS


WATER-MOLD HEAT TRANSFER COEFFICIENT, BTU/HR-SQ FT- DEG F =      3000
THERMAL CONDUCTIVITY OF MOLD, BTU/HR-FT DEG F =        200
MOLD-SLAB HEAT TRANSFER COEFFICIENT, BTU/HR-SQ FT- DEG F =  300.0000
SPRAY-SLAB HEAT TRANSFER COEFFICIENT, BTU/HR-SQ FT- DEG F =      1500
THERMAL CONDUCTIVITY OF STEEL, BTU/HR-FT-DEG F =        25
MOLD LENGTH, FT =  5.00
MOLD THICKNESS, IN =   .50
SLAB THICKNESS, IN =  7.00
SPRAY LENGTH, FT =  4.50
SLAB VELOCITY, FT/MIN =  2.50
DENSITY OF STEEL, LB/CU FT =   490
WATER TEMPERATURE, DEG F =  100
LIQUIDUS TEMPERATURE OF STEEL, DEG F =  2760
TAPPING TEMPERATURE OF STEEL, DEG F =  2840
HEAT OF FUSION OF STEEL, BTU/LB =   118
SPECIFIC HEAT OF LIQUID STEEL, BTU/LB-DEG F= .1840
SPECIFIC HEAT OF SOLID STEEL, BTU/LB-DEG F = .1550
INCREMENT OF FREEZING THICKNESS, IN = .0100
ITERATIONS FOR PRINTOUT =  5
```

TABLE II

CALCULATED RESULTS

TEMPERATURE, F								
T MOLD-W	T MOLD-S	T SLAB-M	Q, BTU	Q REQD, BTU	TIME, SEC	DISTANCE, FT	LENGTH, FT	THICKNESS,
319.3814	456.4948	2650.3092	658144	57.67	.31542	.01314	.06311	.05000
310.6931	442.3762	2549.3069	632079	60.86	.34664	.01444	.13273	.10000
302.6667	429.3333	2456.0000	608000	63.81	.37785	.01574	.20884	.15000
295.2294	417.2477	2369.5413	585688	66.55	.40906	.01704	.29146	.20000
288.3186	406.0177	2289.2035	564956	69.09	.44027	.01834	.38059	.25000
281.8803	395.5556	2214.3590	545641	71.46	.47148	.01965	.47621	.30000
275.8678	385.7851	2144.4629	527603	73.67	.50269	.02095	.57834	.35000
270.2400	376.6400	2079.0400	510720	75.74	.53391	.02225	.68697	.40000
264.9612	368.0620	2017.6745	494884	77.69	.56512	.02355	.80210	.45000
260.0000	360.0000	1960.0001	480000	79.51	.59633	.02485	.92373	.50000
255.3285	352.4088	1905.6935	465985	81.23	.62754	.02615	1.05187	.55000
250.9220	345.2482	1854.4682	452766	82.85	.65875	.02745	1.18651	.60000
246.7586	338.4828	1806.0691	440276	84.38	.68996	.02875	1.32765	.65000
242.8188	332.0806	1760.2686	428456	85.83	.72118	.03005	1.47530	.70000
239.0850	326.0131	1716.8629	417255	87.20	.75239	.03135	1.62944	.75000
235.5414	320.2548	1675.6690	406624	88.51	.78360	.03265	1.79009	.80000
232.1739	314.7826	1636.5219	396522	89.75	.81481	.03395	1.95724	.85000
228.9697	309.5758	1599.2729	386909	90.93	.84602	.03525	2.13090	.90000
225.9172	304.6154	1563.7872	377752	92.05	.87723	.03655	2.31105	.95000
223.0058	299.8844	1529.9424	369017	93.12	.90845	.03785	2.49771	1.00000
220.2260	295.3673	1497.6274	360678	94.14	.93966	.03915	2.69087	1.05000
217.5691	291.0498	1466.7406	352707	95.12	.97087	.04045	2.89054	1.10000
215.0271	286.9190	1437.1895	345081	96.06	1.00208	.04175	3.09670	1.15000
212.5926	282.9630	1408.8892	337778	96.95	1.03330	.04305	3.30937	1.20000
210.2591	279.1710	1381.7620	330777	97.81	1.06450	.04435	3.52854	1.25000
208.0203	275.5330	1355.7364	324061	98.63	1.09572	.04565	3.75422	1.30000
205.8707	272.0398	1330.7466	317612	99.42	1.12693	.04696	3.98639	1.35000
203.8049	268.6830	1306.7321	311415	100.18	1.15814	.04826	4.22507	1.40000
201.8182	265.4546	1283.6367	305455	100.91	1.18935	.04956	4.47025	1.45000
199.9061	262.3475	1261.4088	299718	101.62	1.22056	.05086	4.72193	1.50000
198.0646	259.3549	1240.0004	294194	102.30	1.25177	.05216	4.98012	1.55000
197.7043	258.7696	1235.8130	293113	102.43	1.25802	.05242	5.00000	1.55379
		393.3082	439962	129.09	1.05628	.04401	5.21746	1.61379
		385.4396	428159	129.34	1.08749	.04531	5.44142	1.66379
		377.9822	416973	129.57	1.11870	.04661	5.67188	1.71379
		370.9045	406357	129.80	1.14991	.04791	5.90884	1.76379
		364.1782	396267	130.01	1.18113	.04921	6.15231	1.81379
		357.7779	386667	130.21	1.21234	.05051	6.40228	1.86379
		351.6804	377521	130.41	1.24355	.05181	6.65875	1.91379
		345.8647	368797	130.59	1.27476	.05312	6.92173	1.96379
		340.3117	360468	130.77	1.30598	.05442	7.19120	2.01379
		335.0040	352506	130.93	1.33718	.05572	7.46718	2.06379
		329.9256	344888	131.10	1.36839	.05702	7.74966	2.11379
		325.0621	337593	131.25	1.39961	.05832	8.03865	2.16379
		320.4002	330600	131.40	1.43082	.05962	8.33413	2.21379
		315.9274	323891	131.54	1.46203	.06092	8.63612	2.26379
		311.6325	317449	131.67	1.49324	.06222	8.94461	2.31379
		307.5052	311258	131.81	1.52446	.06352	9.25961	2.36379
		304.3175	306476	131.91	1.54942	.06456	9.50000	2.40127



SOLIDIFICATION IN MOLD

SOLIDIFICATION IN SPRAY

Figure 4. Predicted Profile of Solidification Front in Mold and Spray Sections of a Continuous Casting Strand.

the thickness at the bottom of the water spray is approximately 2.4 inches. This result is in reasonable agreement with the calculations and experimental data of Korotkov, et al.(3)

Several assumptions were made in deriving this unidirectional pseudo steady-state heat transfer simulation. One particular aspect which should be considered is heat transfer between the liquid metal contained in the well and the solidifying shell. This heat transfer was neglected in the present calculation and the temperature in the metal liquid well was assumed to remain constant. This is, of course, not the case in practice, and furthermore, there is some liquid circulation in the well which would promote heat transfer and delay the initial buildup of the shell, at the expense of a decreasing temperature in the metal well. It was not possible in the present case to estimate the influence of this error.

Another rough assumption was that the temperature gradient through the solidified layer of the slab was linear. Although this assumption is known to be in error, the first order correction, i.e., correcting the heat removal term for the energy removed from the solidified layer as it becomes thicker and the temperature gradient levels out, was sufficient to give the liquid-solid interface a nearly parabolic shape in the mold and spray heat transfer zones. A parabolic interface is predicted theoretically if no superheat is present in the liquid by the relationship:

$$X = k\sqrt{\alpha t} \qquad (11)$$

where

k = constant

α = thermal diffusivity, KS/((RHO) * (CPS))

This agreement between the assumed simulation and conditions amenable to theoretical analysis is a good indication that this error did not have a marked influence on the results of the continuous casting simulation.

CONCLUSIONS

1. A unidirectional heat transfer analysis of the continuous casting process has been carried out with reasonable agreement between predicted behavior of the cast slab and that attained in practice.

2. The use of the computer in solving this problem should permit easy extension to modifications in a given casting operation in order to estimate the influences of changes in operating variables.

BIBLIOGRAPHY

1. Journal of Metals, August and September, 1957.

2. Continuous Casting, D. L. McBride, and T. E. Dancy, Editors, AIME, 1962, New York.

3. K. P. Korotkov, H. P. Mayorov, A. A. Skvortsov, and A. D. Akimenko, The Continuous Casting of Steel in Commercial Use, Published in Translation, Pergamon Press, 1960, London.