Technical Note on

Software for ME 487

Report No. UM-MEAM-91-01

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UMKØ524

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1. ABSTRACT

An interactive software package on a Macintosh for ME487 is developed, which involves the thermal analysis of weldments, calculation of residual stresses and distortion, and design of weldments. This technical note provides an overview of the software, and gives step-by-step instructions. Following these procedures, students can use this software easily even when not familiar with the Macintosh, and save a lot of time on the calculations of various aspects of welding problems.

2. INTRODUCTION

This software can solve three aspects of welding problems:

A. Thermal Analysis of Weldments:
Analysis of temperature distribution and cooling rate is an essential aspect of any welding problems, since these affect the final structure of the material as well as the stresses and distortion induced. Simplified closed form analyses have been undertaken.

B. Residual Stresses and Distortion:
The analyses under thermal aspects are extended to include residual stresses and distortion. Since this area is still in its infancy in research, the software developed only encompasses simplified closed form solutions.

C. Design of Weldments:
The design of weldments involves the determination of weld size (crossectional area and length). This software provides a useful tool for students when designing welding systems for application.

Hence the software is divided into the following sections:
(1) crossectional area of fused zone
(2) temperature distribution
(3) peak temperature
(4) determining thin or thick plate
(5) cooling rate
(6) solidification rate
(7) bead width
(8) residual stress
(9) weld distortion
(10) weldment design

3. STEP-BY-STEP INSTRUCTIONS

1. If you use a Macintosh SE computer, swich on the machine.
If you use a Macintosh II, IIx, IIcx, or IIci computer, press the upper rightmost key (marked by a triangle) on the keyboard.

2. Insert the diskette containing the software for ME487.

3. Double click the " ME487 apl " icon to open the file. You will see:

```
**************************************************
      ME487  WELDING  SOFTWARE
**************************************************
              MAIN MENU
--------------------------------------------------------
1) CROSSECTIONAL AREA OF FUSED ZONE
2) TEMPERATURE DISTRIBUTION
3) PEAK TEMPERATURE
4) DETERMINING THIN OR THICK PLATE
5) COOLING RATE
6) SOLIDIFICATION RATE
7) BEAD WIDTH
8) RESIDUAL STRESS
9) WELD DISTORTION
10) WELDMENT DESIGN
--------------------------------------------------------
          0) EXIT
**************************************************
ENTER NUMBER ?
```

4. Enter the corresponding number of the item of interest.

5. Follow the instructions on the screen to response. Be careful of the data type (real or interger) when you enter your input data. If the default value is real, you should enter real data also.

Example: If you see:
WELD DENSITY (kg/m^3) ? (e.g. 8000.0)
where "8000.0" is the default value.
If the value which you are going to enter is the same as the default value, just press <return>, otherwise, you should enter your data, say "5000.0" instead of "5000" to avoid errors.

4. DEMONSTRATION

A_w = crossectional area of fused zone
C = specific heat
d = root opening
E = voltage
h = plate thickness
I = current

K = thermal conductivity
K_0 = modified Bessel function of the 2nd kind and order zero
L = latent heat of fusion
l = weld length
P = applied load
Q = heat input
q_1 = energy required to melt a unit volume of material
R = distance from the fusion zone to the point of interest = |y|-w/2
r = distance from the arc to the point of interest
S = (total) shrinkage
S_0 = first pass shrinkage
T = temperature of the point of interest
T_m = melting temperature
T_0 = ambient temperature
t_s = solidification time
V = welding velocity
W = accumulated weight of weld metal deposited per unit weld length
W_0 = initial W (first pass)
w = bead width
α = $K/\rho C$
ε_A = measured strain (from srrain gauge A)
ε_B = measured strain (from srrain gauge B)
ε_C = measured strain (from srrain gauge C)
ε_x = strain in x-direction
ε_y = strain in y-direction
$\varepsilon_{1,2}$ = principal strain
ρ = weldment density
ρ_w = weld density
υ = poission's ratio
τ_{max} = maximum shear stress
η_1 = heat transfer efficiency
η_2 = melting efficiency

(1) Crossectional Area of Fused Zone

$$A_w = \frac{\eta_1 \eta_2 EI}{q_1 V}$$

where

$$q_1 = \rho_w [\, L + C\,(T_m - T_0)\,]$$

(2) Temperature Distribution

For thick plate (3-Dimensional)

$$T-T_0 = \frac{Q}{2\pi rK} e^{-V\left(\frac{r+x}{2\alpha}\right)}$$

For thin plate (2-Dimensional)

$$T-T_0 = \frac{Q}{2\pi rK} e^{\frac{-vx}{2\alpha}} K_0\left(\frac{-vx}{2\alpha}\right)$$

(3) Peak Temperature

$$\frac{1}{T-T_0} = \frac{4.13\rho hVCR}{Q} + \frac{1}{T_m-T_0}$$

(4) Determining Thin or Thick Plate

$$\tau = h\sqrt{\frac{\rho CV\,(T-T_0)}{Q}}$$

Thin plate when $\tau < 0.6$

Thick plate when $\tau > 0.9$

(5) Cooling Rate

For thick plate (3-Dimensional)

$$\frac{dT}{dt} = \frac{-2\pi KV}{Q}\,(T-T_0)^2$$

For thin plate (2-Dimensional)

$$\frac{dT}{dt} = -2\pi K\rho C\left(\frac{Vh}{Q}\right)^2 (T-T_0)^3$$

(6) Solidification Rate

$$t_s = \frac{LQ}{2\pi K\rho CV(T-T_m)^2}$$

(7) Bead Width

For thick plate (3-Dimensional)

$$Q = 1.25\,\pi wKT_m\left(0.4 + \frac{Vw}{4\alpha}\right)$$

For thin plate (2-Dimensional)

$$Q = 8KhT_m \left(0.2 + \frac{Vw}{4\alpha} \right)$$

(8) Residual Stress

$$\varepsilon_A = \varepsilon_x \cos^2 \theta_A + \varepsilon_y \sin^2 \theta_A + \gamma_{xy} \sin \theta_A \cos^2 \theta_A$$
$$\varepsilon_B = \varepsilon_x \cos^2 \theta_B + \varepsilon_y \sin^2 \theta_B + \gamma_{xy} \sin \theta_A \cos^2 \theta_B$$
$$\varepsilon_C = \varepsilon_x \cos^2 \theta_C + \varepsilon_y \sin^2 \theta_C + \gamma_{xy} \sin \theta_A \cos^2 \theta_C$$

$$\varepsilon_{1,2} = \frac{\varepsilon_x + \varepsilon_y}{2} \pm \frac{1}{2} \sqrt{(\varepsilon_x - \varepsilon_y)2 + \gamma_{xy}^2}$$

$$\sigma_1 = - \frac{E}{1 - \upsilon^2} (\varepsilon_1 + \upsilon \varepsilon_2)$$
$$\sigma_2 = - \frac{E}{1 - \upsilon^2} (\varepsilon_2 + \upsilon \varepsilon_1)$$
$$\tau_{max} = | \sigma_1 - \sigma_2 | / 2$$

(9) Weld Distortion

(1) Transverse Shrinkage

(a) Butt Welds

For Single Pass

$$S = \alpha \frac{A}{h} + \beta d$$

where $\alpha = 0.2$ for inch units (5.16 for mm units)

For Multipasss Weld

$$S = S_0 + b \log \frac{W}{W_0}$$

b =constant

(b) Fillet Welds

$$S = \alpha \frac{\text{Leg of Fillet}}{\text{Plate thickness}} \quad \text{(inches)}$$

$\alpha = 0.06$ for lap-joint, 0.04 for T-joint

(2) Longitudinal Shrinkage

$$S = \frac{0.12IL}{10^5 h} \quad \text{(inches)}$$

(3) Angular Distortion

$$\delta = \phi l\left[\, 0.25 - \left(\frac{x}{l} - 0.5\right)^2 \,\right]$$

$$\text{where } \phi = \frac{\phi_0}{1+\frac{2D}{lC}}, \quad D = \frac{Eh^3}{12(1-\upsilon^2)}, \quad C = \frac{h^4}{1+0.2W}$$

(10) Weldment Design

(1) Butt Welds

$$\sigma = \frac{p}{hl}, \quad \tau = \frac{p}{hl}$$

(2) Fillet Welds

<u>For Tension Test</u>

$$\tau = \frac{p}{0.707hl}$$ where h = weld leg

<u>For Torsion Test</u>

Direct shear $\tau_1 = P / A$ Where A = throat area

Shear due to torsion $\tau_2 = Tr / J$

where T = Torque = PL

J = area polar moment of inertia of weld group about centroid

<u>For Bending Test</u>

Direct shear $\tau_1 = P / A$

Bending Stress $\sigma = \frac{MC}{I}$

where M = PA, C = d / 2 + h

$I = 0.707\, h\, I_u$

I_u = unit area moment of inertia

APPENDIX

```
      PROGRAM ME487
      DOUBLE PRECISION BK,BI,BJ,RKK,SS,A,EX,THK
1     WRITE (9,10)
10    FORMAT ('*******************************************'//
     ;        '           ME487   WELDING   SOFTWARE       '//
     ;        '*******************************************'//
     ;        '               MAIN MENU                   '//
     ;        '-------------------------------------------'/
     ;        ' 1)  CROSSECTIONAL AREA OF FUSED ZONE       '/
     ;        ' 2)  TEMPERATURE DISTRIBUTION               '/
     ;        ' 3)  PEAK TEMPERATURE                       '/
     ;        ' 4)  DETERMINING THIN OR THICK PLATE        '/
     ;        ' 5)  COOLING RATE                           '/
     ;        ' 6)  SOLIDIFICATION RATE                    '/
     ;        ' 7)  BEAD WIDTH                             '/
     ;        ' 8)  RESIDUAL STRESS                        '/
     ;        ' 9)  WELD DISTORTION                        '/
     ;        '10)  WELDMENT DESIGN                        '/
     ;        '-------------------------------------------'/
     ;        '                0)  EXIT                    '/
     ;        '*******************************************'//
     ;        ' ENTER NUMBER ?                             '/)
      PI=3.1415926
11    FORMAT (/A50)
21    FORMAT (F9.4)
22    FORMAT (F12.5)
20    READ (9,30) I
30    FORMAT (I2)
      GO TO (100,200,300,400,500,600,700,800,900,1000) I
      GO TO 9999
C-------------------------NO.1-------------------------------------
100   WRITE (9,11) 'HEAT TRANSFER EFFICIENCY ? (e.g. 0.95)'
      READ (9,21) F1
      IF (F1.EQ.0.) F1=.95
      WRITE (9,11) 'MELTING EFFICIENCY ? (e.g. 0.97)'
      READ (9,21) F2
      IF (F2.EQ.0.) F2=.97
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 8000.0)'
      READ (9,22) THO
```

```
      IF (THO.EQ.0.) THO=8000.
      THO=THO/1000000000.
      WRITE (9,11) 'SPECIFIC HEAT (kJ/kg.K) ?  (e.g. 0.850)'
      READ (9,22) C
      IF (C.EQ.0.) C=.85
      C=C*1000
      WRITE (9,11) 'LATENT HEAT (kJ/kg) ?  (e.g. 272.0)'
      READ (9,21) HL
      IF (HL.EQ.0.) HL=272.
      HL=HL*1000.
      WRITE (9,11) 'MELTING TEMPERATURE (C) ?  (e.g. 1465.0)'
      READ (9,21) TM
      IF (TM.EQ.0.) TM=1465.
      WRITE (9,11) 'AMBIENT TEMPERATURE (C) ?  (e.g. 20.0)'
      READ (9,21) TA
      IF (TA.EQ.0.) TA=20.
      WRITE (9,11) 'CURRENT (Amp) ?  (e.g. 250.0)'
      READ (9,21) EI
      IF (EI.EQ.0.) EI=250.
      WRITE (9,11) 'VOLTAGE (Volts) ?  (e.g. 30.0)'
      READ (9,21) E
      IF (E.EQ.0.) E=30.
      WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 12.0)'
      READ (9, 22) V
      IF (V.EQ.0.) V=12.
      Q=THO*(HL+C*(TM-TA))
      AW=(F1*F2*E*EI)/(Q*V)
      WRITE (9,190) AW
190   FORMAT (/'CROSSECTIONAL AREA =' F10.3, ' (mm^2)'/)
      PAUSE
      GO TO 1
C---------------------NO. 2----------------------------------------
200   WRITE (9,11) 'ENTER DIMENSION ? (2=THIN PLATE, 3=THICK PLATE)'
      READ (9,202) I
      IF (I.EQ.0) I=2
202   FORMAT (I1)
      WRITE (9,11) 'THERMAL CONDUCTIVITY (J/s.mm.C) ? ( e.g. 0.05)'
      READ (9,21) THK
      IF (THK.EQ.0.) THK=.05
```

```
      WRITE (9,11) 'AMBIENT TEMPERATURE (C) ? (e.g. 25.0)'
      READ (9,21) TA
      IF (TA.EQ.0.) TA=25.
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 8000.0)'
      READ (9,22) THO
      IF (THO.EQ.0.) THO=8000.
      THO=THO/1000000000.
      WRITE (9,11) 'SPECIFIC HEAT (kJ/kg.K) ?  (e.g. 0.850)'
      READ (9,21) C
      IF (C.EQ.0.) C=.85
      C=C*1000.
      ALPHA=THK/(THO*C)
      WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 10.0)'
      READ (9, 21) V
      IF (V.EQ.0.) V=10.
      WRITE (9,205)
205   FORMAT (/'ENTER HEAT-INPUT OR VOLTAGE-CURRENT ? ',
     ;        '1=HEAT-INPUT, 2=VOLATGE-CURRENT')
      READ (9,30) K
      IF (K.EQ.0) K=1
      GO TO (206,207) K
206   WRITE (9,11) 'HEAT INPUT (J/s) ? (e.g. 6000.0)'
      READ (9,22) Q
      IF (Q.EQ.0.) Q=6000.
      GO TO 209
207   WRITE (9,11) 'VOLTAGE (Volts) ? (e.g. 30.0)'
      READ (9,21) E
      IF (E.EQ.0.) E=30.
      WRITE (9,11) 'CURRENT (Amp) ? (e.g. 200.)'
      READ (9,21) EI
      IF (EI.EQ.0.) EI=200.
      WRITE (9,11) 'HEAT TRANSFER EFFICIENCY ? (e.g. 1.0)'
      READ (9,21) F1
      IF (F1.EQ.0.) F1=1.
      Q=F1*E*EI
209   WRITE (9,210)
210   FORMAT (/'COORINATES W.R.T. HEAT SOURCE. X (mm)= ? (e.g. -8.0)'
     ;        /'!! X<0 IF BEHIND THE HEAT SOURCE')
      READ (9,21) X
      IF (X.EQ.0.) X=-8.0
```

```
      WRITE (9,11) 'Y (mm) = ? (e.g. 5.0)'
      READ (9,21) Y
      IF (Y.EQ.0.) Y=5.0
      IF (I.NE.3) GO TO 270
C---------------------3-D
      WRITE (9,11) 'Z (mm)= ? (e.g. 3.0) '
      READ (9,21) Z
      IF (Z.EQ.0.) Z=5.0
      R=(X**2+Y**2+Z**2)**.5
      EX=-V*(R+X)/(2.*ALPHA)
      T=Q/(2.*PI*R*THK)*EXP(EX) + TA
      WRITE (9,265) T
265   FORMAT (/'3-D TEMPERATURE = ' F8.3, ' (C)')
      PAUSE
      GO TO 1
270   IF (I.NE.2) GO TO 1
C---------------------2-D
      WRITE (9,11) 'THICKNESS (mm) =? (e.g. 8.0) '
      READ (9,22) H
      IF (H.EQ.0.) H=8.0
      R=(X**2+Y**2)**.5
      EX=V*X/(2.*ALPHA)
      A=V*R/(2.*ALPHA)
      BI=0
      BJ=0
      DO 295 K=1,70
           RKK=1
           SS=0
                DO 285 I=1,K
                     RKK=RKK*I
                     S=I
                     SS=SS+1./S
285                  CONTINUE
           RK=K
           BI=BI+1./(RKK*RKK)*((A/2.)**(2.*RK))
           BJ=BJ+((A/2.)**(2.*RK))/(RKK*RKK)*SS
295   CONTINUE
      BK=-(DLOG(A/2.)+0.5772157)*(BI+1.)+BJ
      T=Q/(2.*PI*THK*H)*EXP(-EX)*BK+TA
```

```
      WRITE (9,299) T
299   FORMAT (/'2-D TEMPERATURE = ' F8.3, ' (C)')
      PAUSE
      GO TO 1
C-----------------------------NO.3-----------------------------------
300   WRITE (9,11) 'MELTING TEMPERATURE (C) ? (e.g. 1500.0)'
      READ (9,21) TM
      IF (TM.EQ.0.) TM=1500.
      WRITE (9,11) 'AMBIENT TEMPERATURE (C) ? (e.g. 25.0)'
      READ (9,21) TA
      IF (TA.EQ.0.) TA=25.
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 8000.0)'
      READ (9,22) THO
      IF (THO.EQ.0.) THO=8000.
      THO=THO/1000000000.
      WRITE (9,11) 'SPECIFIC HEAT (kJ/kg.K) ?  (e.g. 0.850)'
      READ (9,22) C
      IF (C.EQ.0.) C=.85
      C=C*1000.
      ALPHA=THK/(THO*C)
      WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 10.0)'
      READ (9, 21) V
      IF (V.EQ.0.) V=10.
      WRITE (9,305)
305   FORMAT (/'ENTER HEAT-INPUT OR VOLTAGE-CURRENT ? ',
     ;        '1=HEAT-INPUT, 2=VOLATGE-CURRENT')
      READ (9,30) K
      IF (K.EQ.0) K=1
      GO TO (306,307) K
306   WRITE (9,11) 'HEAT INPUT (J/s) ? (e.g. 6000.0)'
      READ (9,22) Q
      IF (Q.EQ.0.) Q=6000.
      GO TO 309
307   WRITE (9,11) 'VOLTAGE (Volt) ? (e.g. 30.0)'
      READ (9,21) E
      IF (E.EQ.0.) E=30.
      WRITE (9,11) 'CURRENT (Amp) ? (e.g. 200.)'
      READ (9,21) EI
      IF (EI.EQ.0.) EI=200.
      WRITE (9,11) 'HEAT TRANSFER EFFICIENCY ? (e.g. 1.0)'
```

```
      READ (9,21) F1
      IF (F1.EQ.0.) F1=1.
      Q=F1*E*EI
309   WRITE (9,11) 'THICKNESS(mm) =? (e.g.8.0) '
      READ (9,21) H
      IF (H.EQ.0.) H=8.
      WRITE (9,11) 'DISTANCE FROM FUSION ZONE (mm) ? (e.g. 3.42) '
      READ (9,21) R
      IF (R.EQ.0.) R=3.42
      TI= 4.13*THO*H*V*C*R/Q + 1/(TM-TA)
      TP= TA + 1./TI
      WRITE (9,390) TP
390   FORMAT (/'PEAK TEMPERATURE = ' F10.3, ' (C)')
      PAUSE
      GO TO 1
C-------------------------NO.4-------------------------------------
400   WRITE (9,11) ' TEMPERATURE (C) ? (e.g. 600.0)'
      READ (9,21) T
      IF (T.EQ.0.) T=600.
      WRITE (9,11) 'AMBIENT TEMPERATURE (C) ? (e.g. 25.0)'
      READ (9,21) TA
      IF (TA.EQ.0.) TA=25.
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 7000.0)'
      READ (9,22) THO
      IF (THO.EQ.0.) THO=7000.
      THO=THO/1000000000.
      WRITE (9,11) 'SPECIFIC HEAT (kJ/kg.K) ?  (e.g. 0.50)'
      READ (9,21) C
      IF (C.EQ.0.) C=.5
      C=C*1000.
      ALPHA=THK/(THO*C)
      WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 6.0)'
      READ (9, 21) V
      IF (V.EQ.0.) V=6.
      WRITE (9,405)
405   FORMAT (/'ENTER HEAT-INPUT OR VOLTAGE-CURRENT ? ',
     ;        '1=HEAT-INPUT, 2=VOLATGE-CURRENT')
      READ (9,30) K
      IF (K.EQ.0) K=2
```

```
      GO TO (406,407) K
406   WRITE (9,11) 'HEAT INPUT (J/s) ? (e.g. 6750.0)'
      READ (9,22) Q
      IF (Q.EQ.0.) Q=6750.
      GO TO 409
407   WRITE (9,11) 'VOLTAGE (Volt) ? (e.g. 30.0)'
      READ (9,21) E
      IF (E.EQ.0.) E=30.
      WRITE (9,11) 'CURRENT (Amp) ? (e.g. 250.)'
      READ (9,21) EI
      IF (EI.EQ.0.) EI=250.
      WRITE (9,11) 'HEAT TRANSFER EFFICIENCY ? (e.g. 0.9)'
      READ (9,21) F1
      IF (F1.EQ.0.) F1=.9
      Q=F1*E*EI
409   WRITE (9,11) 'THICKNESS (mm) = ? (e.g.3.0) '
      READ (9,21) H
      IF (H.EQ.0.) H=3.
      TAU=H*(THO*C*V*(T-TA)/Q)**0.5
      WRITE (9,460) TAU
460   FORMAT (/' TAU = ' F6.3)
      IF (TAU.LT.0.6) THEN
         WRITE (9,11) 'THIN PLATE'
               ELSE IF (TAU.GT.0.9) THEN
                   WRITE (9,11) 'THICK PLATE'
               ELSE
                   WRITE (9,11) 'UNDETERMINED'
      ENDIF
      PAUSE
      GO TO 1
C-------------------------N0.5---------------------------------------
500   WRITE (9,11) ' TEMPERATURE (C) ? (e.g. 400.0)'
      READ (9,21) T
      IF (T.EQ.0.) T=400.
      WRITE (9,11) 'AMBIENT TEMPERATURE (C) ? (e.g. 30.0)'
      READ (9,22) TA
      IF (TA.EQ.0.) TA=30.
      WRITE (9,505)
505   FORMAT (/'ENTER HEAT-INPUT OR VOLTAGE-CURRENT ? ',
     ;         '1=HEAT-INPUT, 2=VOLATGE-CURRENT')
```

```
      READ (9,30) K
      IF (K.EQ.0) K=2
      GO TO (506,507) K
506   WRITE (9,11) 'HEAT INPUT (J/s) ? (e.g. 6375.0)'
      READ (9,22) Q
      IF (Q.EQ.0.) Q=6375.
      GO TO 509
507   WRITE (9,11) 'VOLTAGE (Volt) ? (e.g. 30.0)'
      READ (9,21) E
      IF (E.EQ.0.) E=30.
      WRITE (9,11) 'CURRENT (Amp) ? (e.g. 250.)'
      READ (9,21) EI
      IF (EI.EQ.0.) EI=250.
      WRITE (9,11) 'HEAT TRANSFER EFFICIENCY ? (e.g. 0.85)'
      READ (9,21) F1
      IF (F1.EQ.0.) F1=.85
      Q=F1*E*EI
509   WRITE (9,11) 'THERMAL CONDUCTIVITY (J/s.mm.C) ? ( e.g. 0.0456)'
      READ (9,22) THK
      IF (THK.EQ.0.) THK=.0456
      WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 8.0)'
      READ (9, 21) V
      IF (V.EQ.0.) V=8.
      WRITE (9,11) 'ENTER DIMENSION ? (2=THIN PLATE, 3=THICK PLATE)'
      READ (9,30) I
      IF (I.EQ.0) I=2
      IF (I.NE.3) GO TO 550
C----------------------3-D
      DT=-2*PI*THK*V/Q*(T-TA)**2
      WRITE (9,520) DT
520   FORMAT (/'COOLING RATE = ' F10.3, ' (C/s)')
      PAUSE
      GO TO 1
550   IF (I.NE.2) GO TO 1
C----------------------2-D
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 7870.0)'
      READ (9,22) THO
      IF (THO.EQ.0.) THO=7870.
      THO=THO/1000000000.
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      WRITE (9,11) 'SPECIFIC HEAT (kJ/kg.K) ?  (e.g. 0.595)'
      READ (9,21) C
      IF (C.EQ.0.) C=.595
      C=C*1000.
      WRITE (9,11) 'THICKNESS (mm) = ?  (e.g.9.0) '
      READ (9,22) H
      IF (H.EQ.0.) H=9.
      DT=-2.*PI*THK*THO*C*(V*H/Q)**2*(T-TA)**3
      WRITE (9,599) DT
599   FORMAT (/'COOLING RATE = ' F10.3, ' (C/s)' )
      PAUSE
      GO TO 1
C-------------------------NO.6-----------------------------------
600   WRITE (9,11) 'SPECIFIC HEAT (kj/kg.K) ?  (e.g. 0.5)'
      READ (9,21) C
      IF (C.EQ.0.) C=.5
      C=C*1000.
      WRITE (9,11) 'LATENT HEAT (j/kg) ?  (e.g. 2.5)'
      READ (9,21) HL
      IF (HL.EQ.0.) HL=2.5
      WRITE (9,11) 'MELTING TEMPERATURE (C) ?  (e.g. 1600.0)'
      READ (9,21) TM
      IF (TM.EQ.0.) TM=1600.
      WRITE (9,11) 'AMBIENT TEMPERATURE (C) ?  (e.g. 25.0)'
      READ (9,21) TA
      IF (TA.EQ.0.) TA=25.
      WRITE (9,605)
605   FORMAT (/'ENTER HEAT-INPUT OR VOLTAGE-CURRENT ? ',
     ;         '1=HEAT-INPUT, 2=VOLATGE-CURRENT')
      READ (9,30) K
      IF (K.EQ.0) K=2
      GO TO (606,607) K
606   WRITE (9,11) 'HEAT INPUT (J/s) ? (e.g. 6750.0)'
      READ (9,22) Q
      IF (Q.EQ.0.) Q=6750.
      GO TO 609
607   WRITE (9,11) 'VOLTAGE (Volt) ? (e.g. 30.0)'
      READ (9,21) E
      IF (E.EQ.0.) E=30.
```

```
      WRITE (9,11) 'CURRENT (Amp) ? (e.g. 250.)'
      READ (9,21) EI
      IF (EI.EQ.0.) EI=250.
      WRITE (9,11) 'HEAT TRANSFER EFFICIENCY ? (e.g. 0.9)'
      READ (9,21) F1
      IF (F1.EQ.0.) F1=.9
      WRITE (9,11) 'MELTING EFFICIENCY ? (e.g. 1.0)'
      READ (9,21) F2
      IF (F2.EQ.0.) F2=1.
      Q=F1*F2*E*EI
 609  WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 6.0)'
      READ (9, 21) V
      IF (V.EQ.0.) V=6.
      WRITE (9,11) 'THERMAL CONDUCTIVITY (J/s.mm.C) ? ( e.g. 0.025)'
      READ (9,21) THK
      IF (THK.EQ.0.) THK=.025
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 7000.0)'
      READ (9,22) THO
      IF (THO.EQ.0.) THO=7000.
      THO=THO/1000000000.
      T=2.*PI*THK*THO*C*V*(TM-TA)**2
      TIME=HL*Q/T
      WRITE (9,690) TIME
 690  FORMAT (/'SOLIDIFICATION TIME = ', F7.3, ' (sec)' )
      PAUSE
      GO TO 1
C-------------------------NO.7-------------------------------------
 700  WRITE (9,11) 'ENTER DIMENSION ? (2=THIN PLATE, 3=THICK PLATE)'
      READ (9,702) I
 702  FORMAT (I1)
      IF (I.EQ.0) I=2
      WRITE (9,11) 'MELTING TEMPERATURE (C) ?  (e.g. 1500.0)'
      READ (9,21) TM
      IF (TM.EQ.0.) TM=1500.
      WRITE (9,11) 'THERMAL CONDUCTIVITY (J/s.mm.C) ? ( e.g. 0.05)'
      READ (9,21) THK
      IF (THK.EQ.0.) THK=.05
      WRITE (9,11) 'WELD DENSITY (kg/m^3) ?  (e.g. 8000.0)'
      READ (9,22) THO
      IF (THO.EQ.0.) THO=8000.
```

```
      THO=THO/1000000000.
      WRITE (9,11) 'SPECIFIC HEAT (kj/kg.K) ?  (e.g. 0.850)'
      READ (9,21) C
      IF (C.EQ.0.) C=.85
      C=C*1000.
      ALPHA=THK/(THO*C)
      WRITE (9,11) 'WELDING SPEED (mm/s) ?  (e.g. 10.0)'
      READ (9, 21) V
      IF (V.EQ.0.) V=10.
      WRITE (9,11) 'HEAT INPUT (j/s) ? (e.g. 6000.0)'
      READ (9,22) Q
      IF (Q.EQ.0.) Q=6000.
      IF (I.NE.3) GO TO 760
C-----------------3-D
      CB=1.6*ALPHA/V
      CC=4.*ALPHA*Q/(1.25*PI*THK*TM*V)
      W=.5*(-CB+(CB**2.+4.*CC)**.5)
      WRITE (9,750) W
750   FORMAT (/'BEAD WIDTH = ' F10.3, ' (mm)')
      PAUSE
      GO TO 1
760   IF (I.NE.2) GO TO 1
C-----------------2-D
      WRITE (9,11) 'THICKNESS (mm) = ?  (e.g. 10.0) '
      READ (9,21) H
      IF (H.EQ.0.) H=10.
      W=(4.*ALPHA/V)*(Q/(8.*THK*H*TM)-.2)
      WRITE (9,790) W
790   FORMAT (/'BEAD WIDTH = ' F10.3, ' (mm)')
      PAUSE
      GO TO 1
C-------------------------NO.8-----------------------------------
800   WRITE (9,805)
805   FORMAT ('************************************************'//
     ;        '        ARRANGEMENT OF STRAIN GAUGES             '/
     ;        '-------------------------------------------------'/
     ;        ' 1) DELTA OR STAR ROSETTE                        '/
     ;        ' 2) RECTANGULAR ROSETTE                          '/
     ;        '-------------------------------------------------'/
```

```
     ;         '       0) MAIN MENU                    '/
     ;         '*********************************************'//
     ;         ' ENTER NUMBER ?                                '/)
      READ (9,30) II
      IF (II.EQ.0) GO TO 1
      WRITE (9,11) 'ELASTIC MODULUS (GPa) ? (e.g. 200.) '
      READ (9,22) E
      IF (E.EQ.0.) E=200.
      WRITE (9,11) 'POISSON RATIO ? (e.g. 0.3) '
      READ (9,21) V
      IF (V.EQ.0.) V=.3
      IF (II.NE.1) GO TO 830
C-----------------------------------DELTA ROSETTE
      WRITE(9,11) 'MEASURED STRAIN (0-DEGREE-GAGE) ? (e.g. 0.000750)'
      READ (9,810) EA
810   FORMAT (F8.6)
      IF (EA.EQ.0.) EA=.000750
      WRITE(9,11) 'MEASURED STRAIN (120-DEGREE-GAGE) ? (e.g.0.000283)'
      READ (9,810) EB
      IF (EB.EQ.0.) EB=.000283
      WRITE(9,11) 'MEASURED STRAIN (240-DEGREE-GAGE) ? (e.g.0.000500)'
      READ (9,810) EC
      IF (EC.EQ.0.) EC=.000500
      EX=EA
      EY=(2.*(EB+EC)-EA)/3.
      EXY=2.*(EC-EB)/1.732
      GO TO 840
C-----------------------------------RECTANGULAR ROSETTE
830   WRITE(9,11) 'MEASURED STRAIN (0-DEGREE-GAGE) ? (e.g. 0.000750)'
      READ (9,810) EA
      IF (EA.EQ.0.) EA=.000750
      WRITE(9,11) 'MEASURED STRAIN (45-DEGREE-GAGE) ? (e.g.0.000283)'
      READ (9,810) EB
      IF (EB.EQ.0.) EB=.000283
      WRITE(9,11) 'MEASURED STRAIN (90-DEGREE-GAGE) ? (e.g.0.000500)'
      READ (9,810) EC
      IF (EC.EQ.0.) EC=.000500
      EX=EA
      EY=EC
      EXY=2.*EB-EA-EC
```

```
C-------------------------CALCULATE PRINCIPAL STRAIN
840   E1=(EX+EY)/2. + SQRT(((EX-EY)/2.)**2+EXY**2)
      E2=(EX+EY)/2. - SQRT(((EX-EY)/2.)**2+EXY**2)
C-------------------------CALCULATE PRINCIPAL STRESS
      S1=-E/(1.-V**2)*(E1+V*E2)*1000.
      S2=-E/(1.-V**2)*(E2+V*E2)*1000.
      TAU=(S1-S2)/2.
      WRITE (9,890) S1,S2,TAU
890   FORMAT (/'PRINCIPAL RESIDUAL STRESS 1:',F8.2,' (MPa)',
     ;        /'PRINCIPAL RESIDUAL STRESS 2:',F8.2,' (MPa)',
     ;        /'MAXIMAL SHEAR STRESS:',F8.2,' (MPa)' )
      PAUSE
      GO TO 800
C-------------------------N0.9-----------------------------------
900   WRITE (9,905)
905   FORMAT ('************************************************'//
     ;        '         WELD DISTORTION MENU                   '/
     ;        '----------------------------------------------'/
     ;        ' 1) TRANSVERSE  SHRINKAGE                     '/
     ;        ' 2) LONGITUDINAL SHRINKAGE                    '/
     ;        ' 3) ANGULAR DISTORTION                        '/
     ;        '----------------------------------------------'/
     ;        '              0) MAIN MENU                    '/
     ;        '************************************************'//
     ;        ' ENTER NUMBER ?                               '/)
      READ (9,30) II
      IF (II.EQ.0) GO TO 1
      GO TO (910,950,970) II
C---------------------------------------- 1) TRANSVERSE SHRINKAGE
910   WRITE (9,915)
915   FORMAT ('************************************************'//
     ;        '        TRANSVERSE SHRINKAGE MENU               '/
     ;        '----------------------------------------------'/
     ;        ' 1) BUTT WELDS                                '/
     ;        ' 2) FILLET WELDS                              '/
     ;        '----------------------------------------------'/
     ;        '       0) WELD DISTORTION MENU                 '/
     ;        '************************************************'//
     ;        ' ENTER NUMBER ?                               '/)
```

```
      READ (9,30) III
      IF (III.EQ.0) GO TO 900
      GO TO (920,940) III
C----------------------------- 1)BUTT WELDS
920   WRITE (9,11) 'SINGLE OR MULTIPASS ? 1=SINGLE, 2=MULTIPASS'
      READ (9,30) J
      IF (J.NE.1) GO TO 930
C-------------- SINGLE PASS
      WRITE (9,11) 'WELD CROSSECTIONAL AREA (in^2) ? (e.g. 0.207)'
      READ (9,21) A
      IF (A.EQ.0.) A=.207
      WRITE (9,11)  'THICKNESS (in) ? (e.g. 0.5)'
      READ (9,21) H
      IF (H.EQ.0.) H=.5
      WRITE (9,11) 'ROOT OPENING (in) ? (e.g. 0.125)'
      READ (9,21) D
      IF (D.EQ.0.) D=.125
      S=.2*A/H + .05*D
      WRITE (9,925) S
925   FORMAT (/'SHRINKAGE =',F8.4,' (in) ')
      PAUSE
      GO TO 910
C---------------------MULTIPASS
930   WRITE (9,11) 'FIRST PASS SHRINKAGE (in) ? (e.g. 0.111)'
      READ (9,21) S0
      IF (S0.EQ.0.) S0=.111
      WRITE (9,11) 'WELD WEIGNT IN 1st-PASS (lb/in) ? (e.g.0.035)'
      READ (9,21) W0
      IF (W0.EQ.0.) W0=.035
      WRITE (9,11) 'ACCUMULATED WELD WEIGNT (lb/in) ? (e.g.0.065)'
      READ (9,21) W
      IF (W.EQ.0.) W=.065
      S=S0 + .37*ALOG(W/W0)
      WRITE (9,935) S
935   FORMAT (/'TOTAL SHRINKAGE =',F8.4,' (in) ')
      PAUSE
      GO TO 910
C------------------------------ 2) FILLET WELDS
940   WRITE (9,11) 'LAP OR T-JOINT ? (1=LAP, 2=T-JOINT) '
      READ (9,30) ILT
```

```
      IF (ILT.EQ.0) ILT=1
      ALPHA=.06
      IF (ILT.EQ.2) ALPHA=.04
      WRITE (9,11) 'PLATE THICKNESS (in) ? (e.g. 0.75)'
      READ (9,21) H
      IF (H.EQ.0.) H=.75
      WRITE (9,11) 'LEG OF FILLET (in) ? (e.g. 0.5)'
      READ (9,21) FL
      IF (FL.EQ.0.) FL=.5
      S=FL/H*ALPHA
      WRITE (9,945) S
945   FORMAT (/'SHRINKAGE = ',F6.3,' (in) ')
      PAUSE
      GO TO 910
C---------------------------------------- 2) LONGITUDINAL SHRINKAGE
950   WRITE (9,11) 'CURRENT (amp) ? (e.g. 300.)'
      READ (9,21) CI
      IF (CI.EQ.0.) CI=300.
      WRITE (9,11) 'PLATE THICKNESS (in) ? (e.g. 0.75)'
      READ (9,21) H
      IF (H.EQ.0.) H=.75
      WRITE (9,11) 'WELD LENGTH (in) ? (e.g. 20.0)'
      READ (9,21) WL
      IF (WL.EQ.0.) WL=20.
      S=.12*CI*WL/(100000.*H)
      WRITE (9,955) S
955   FORMAT (/'SHRINKAGE = ',F6.3,' (in) ')
      PAUSE
      GO TO 900
C---------------------------------------------- 3) ANGULAR DISTORTION
970   WRITE (9,11) 'ELASTIC MODULUS (GPa) ? (e.g. 206.) '
      READ (9,22) E
      IF (E.EQ.0.) E=200.
      E=E/9.81*1000.
      WRITE (9,11) 'POISSON RATIO ? (e.g. 0.3) '
      READ (9,21) V
      IF (V.EQ.0.) V=.3
      WRITE (9,11) 'LENGH OF SPAN (mm) ? (e.g. 750.)'
      READ (9,21) SL
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```
      IF (SL.EQ.0.) SL=750.
      WRITE (9,11) 'DISTANCE FROM JOINT (mm) ? (e.g. 375.)'
      READ (9,21) X
      IF (X.EQ.0.) X=375.
      WRITE (9,11) 'PLATE THICKNESS (mm) ? (e.g. 19.)'
      READ (9,21) H
      IF (H.EQ.0.) H=19.
      WRITE (9,11) 'WELD WEIGHT (g/cm) ? (e.g. 3.925)'
      READ (9,21) W
      IF (W.EQ.0.) W=3.925
      WRITE(9,11) 'ANGULAR CHANGE IN A FREE JOINT (rad) ? (e.g.0.016)'
      READ (9,21) PHI0
      IF (PHI.EQ.0.) PHI0=.016
      C=H**4/(1.+0.2*W)
      D=E*H**3/(12.*(1-V**2))
      PHI=PHI0/(1.+2*D/(SL*C))
      DELTA=PHI*SL*(.25-(X/SL-.5)**2)
      WRITE (9,975) DELTA
975   FORMAT ('DISTORTION = ',F6.3,' (mm) ')
      PAUSE
      GO TO 900
C-------------------------------N0.10-------------------------------
1000  WRITE (9,1015)
1015  FORMAT ('************************************************'//
     ;        '             WELDMENT DESIGN MENU               '/
     ;        '------------------------------------------------'/
     ;        ' 1) BUTT WELDS                                  '/
     ;        ' 2) FILLET WELDS                                '/
     ;        '------------------------------------------------'/
     ;        '              0) MAIN MENU                      '/
     ;        '************************************************'//
     ;        ' ENTER NUMBER ?                                 '/)
      READ (9,30) II
      IF (II.EQ.0) GO TO 1
      GO TO (1020,1040) II
C------------------------------ 1)BUTT WELDS
1020  WRITE (9,11) 'APPLIED LOAD (lb) ? (e.g. 40000.)'
      READ (9,1025) P
1025  FORMAT (F9.2)
      IF (P.EQ.0.) P=40000.
```

```
      WRITE (9,11) 'PLATE THICKNESS (in) ? (e.g. 0.4)'
      READ (9,21) H
      IF (H.EQ.0.) H=.4
      WRITE (9,11) 'WELD LENGTH (in) ? (e.g. 20.0)'
      READ (9,21) WL
      IF (WL.EQ.0.) WL=20.
      STRESS=P/(H*WL)
      WRITE (9,1030) STRESS
1030  FORMAT (/'STRESS IN WELD = ',F10.2,' (psi) ')
      PAUSE
      GO TO 1000
C---------------------- 2) FILLET WELD
1040  WRITE (9,1045)
1045  FORMAT (/'*******************************************'//
     ;          '         FILLET WELDS DESIGN MENU          '/
     ;          '-----------------------------------------'/
     ;          ' 1) TENSION TEST                           '/
     ;          ' 2) TORSION TEST                           '/
     ;          ' 3) BENDING TEST                           '/
     ;          '-----------------------------------------'/
     ;          '          0) WELD DESIGN MENU              '/
     ;          '*******************************************'//
     ;          ' ENTER NUMBER ?                            '/)
      READ (9,30) II
      IF (II.EQ.0) GO TO 1000
      GO TO (1050,1070,1090) II
C--------------------------- 1) TENSION TEST
1050  WRITE (9,11) 'APPLIED LOAD (lb) ? (e.g. 40000.)'
      READ (9,1055) P
1055  FORMAT (F9.2)
      IF (P.EQ.0.) P=40000.
      WRITE (9,11) 'PLATE THICKNESS (in) ? (e.g. 0.4)'
      READ (9,21) H
      IF (H.EQ.0.) H=.4
      WRITE (9,11) 'WELD LENGTH (in) ? (e.g. 20.0)'
      READ (9,21) WL
      IF (WL.EQ.0.) WL=20.
      STRESS=P/(.707*H*WL)
      WRITE (9,1060) STRESS
```

```
1060  FORMAT (/'SHEAR STRESS IN WELD = ',F10.2,' (psi) ')
      PAUSE
      GO TO 1040
C-------------------------2) TORSION TEST
1070  WRITE (9,11) 'TORQUE (lb-in) ? (e.g. 35900.)'
      READ (9,1075) T
1075  FORMAT (F9.2)
      IF (T.EQ.0.) T=35900.
      WRITE (9,1080)
1080  FORMAT (/'UNIT POLAR MOMENT OF INERTIA OF WELD GROUP',
     ;          'ABOUT CENTROID (in^3) ? (e.g. 20.833)' )
      READ (9,21) PJU
      IF (PJU.EQ.0.) PJU=20.833
      WRITE (9,11) 'WELD LEG (in) ? (e.g. 0.25)'
      READ (9,21) H
      IF (H.EQ.0.) H=.25
      WRITE (9,11) 'DISTANCE FROM CENTROID (in) ? (e.g. 2.15)'
      READ (9,21) R
      IF (R.EQ.0.) R=2.15
      PJ=.707*H*PJU
      TAU=T*R/PJ
      WRITE (9,1085) TAU
1085  FORMAT (/'SHEAR STRESS DUE TO TORSION =',F8.2,' (psi)')
      PAUSE
      GO TO 1040
C--------------------------- 3) BENDING TEST
1090  WRITE (9,11) 'BEAM LENGTH (in) ? (e.g. 15.0)'
      READ (9,21) A
      IF (A.EQ.0.) A=15.
      WRITE (9,11) 'BEAM THICKNESS (in) ? (e.g. 1.)'
      READ (9,21) D
      IF (D.EQ.0.) D=1.
      WRITE (9,11) 'BEAM WIDTH (in) ? (e.g. 10.)'
      READ (9,21)  B
      IF (B.EQ.0.) B=10.
      WRITE (9,11) 'WELD LEG (in) ? (e.g. 0.4)'
      READ (9,21) H
      IF (H.EQ.0.) H=.4
      WRITE (9,11) 'APPLIED LOAD (lb) ? (e.g. 2000.)'
```

```
      READ (9,1095) P
1095  FORMAT (F9.2)
      IF (P.EQ.0.) P=2000.
      SX=P*A*(D/2.+H)/(.707*H*B*D**2/2.)
      SY=0.
      SXY=P/(.707*H*B*2)
      S1=(SX+SY)/2. + SQRT(((SX-SY)/2.)**2+SXY**2)
      S2=(SX+SY)/2. - SQRT(((SX-SY)/2.)**2+SXY**2)
      WRITE (9,1100) S1,S2
1100  FORMAT (/'PRINCIPAL STRESSES =',F11.2,'   AND ',F11.2 ,'(psi)')
      GO TO 1040
C-------------------------END-----------------------------------------
9999  END
```