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Verhoeven, M.M.A.

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Measurement of dynamic force by strain gage methods during dynamic compaction of powder metals by electromagnetic force.

Guest research at the Mechanical Engineering Laboratory, Tsukuba, Japan.

M.M.A. Verhoeven

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Agency of Industrial Science and Technology, Tsukuba Research Center
SUMMARY

For three and a half months, I have been doing guest research at the Mechanical Engineering Laboratory (M.E.L.) in Tsukuba science city.

One part of the research was to assist a master course student from the Chiba Institute of Technology with his analytical research on the dynamic deformation mechanism in powder metals.

The other part, described in this report, was to develop and build an installation to measure the dynamic force by strain gage methods during dynamic compaction of powder metals by electromagnetic force.

In the first part, the installation and all its parts are described and the used strain gage method and data processing are explained.

The second part is about the electromagnetic influence of the coil, used to produce the demanded force, on the strain gage signal (noise). A method to measure the noise is developed and three adjustments are made to reduce the noise. A grounded metal net and aluminium plate are placed to restrict the magnetic field and the two gage wires are twined to reduce the antenna effect. After these three adjustments the signal is also more constant of shape and value, so that it is possible to remove the noise out of the signal by using a computer program. This method and the computer program are also described.

In the third part a new problem occurred; the bending of the punch. With another strain gage arrangement, with two couples of two gages, this problem is eliminated.

The last part is about the final installation. Alas, because of the compression of the powder, the measured noise and the noise during the compaction are not the same, so that there is still an error in the signal.

Despite that the influence of the noise has decreased, there are still a lot of problems caused by the electromagnetic device. A mechanical instead of the electromagnetic device will avoid these problems and is in consequence recommended.
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PREFACE

If you, as a student of the faculty of Mechanical Engineering, department Production technology and Automation, are given the opportunity to do guest research in Japan, world famous for it's high technology, you don’t hesitate but you seize it with both hands. Due to the good relationship of my graduate professor, professor Kals, with the Mechanical Engineering Laboratory (M.E.L.) in Tsukuba, part of the Agency of Industrial Science and Technology (A.I.S.T.) of the Ministry of International Trade and Industry (M.I.T.I.), I was already the fourth student of his section to do a three month’s traineeship in the Plasticity & Forming division of Dr.T.Sano.

My topic was twofold. I assisted a Japanese master course student of the Chiba Institute of Technology, K.Kato, in the last stage of his graduation at the M.E.L. The results of this research are reproduced in his master paper 'Analysis of dynamic deformation mechanism in powder metals' and will be published on the 24th Japanese spring conference for the Technology of Plasticity, 27th may 1993, Tsukuba, Japan, presentation 634. The second part was to do an experiment to measure the dynamic force by strain-gage methods during dynamic compaction by electromagnetic force. The results of this part are described in this report.

My three and a half months in Japan has been a very instructive period for me. Besides the experience of doing experimental research on my own, I have had the opportunity to learn a lot about the Japanese way of living, working and thinking and I even studied Japanese. For this opportunity, I have been given, I want to thank Dr.H.Sato, director general of the M.E.L.; Dr.K.Matsuno, deputy director general of the M.E.L.; Dr.T.Sano, my host, director of the Plasticity & Forming division; all the students and researchers of this division, K.Kato in particular, who have been very friendly and helpful to me and Prof.ir.J.A.G.Kals.

Eindhoven, may 20, 1993.
1. INTRODUCTION

As a part of a project to research the shock wave propagation in metal powders, I was asked to do a dynamic compaction test by electromagnetic force with aluminium-lithium powder. Aluminium-Lithium is a very promising material, but can be produced as a powder only. Compaction is used to make solid samples of the powder. Because of the oxide layer of the particles, which has to be cracked to have a good bond, dynamic compaction is preferred to static compaction. The impact force is measured by strain-gage methods. From previous experiments there was a rough installation and a frame for a computer program. My task was to write the computer program, built everything together and try to improve it.

2. THE INSTALLATION

2.1. THE ORIGINAL INSTALLATION

The original installation was as shown in figure 1. A power source sends a current through the coil, which causes a electromagnetic field. On account of this field the driver, and so the punch move upwards, causing the compaction of the Al-Li powder. The two strain-gages generate a voltage from which the tension and the dynamic force can be calculated.

2.1.1. THE POWER SOURCE AND COIL

The power source is mainly composed of a capacitor bank, a charging unit and switches. Electrical energy stored in the capacitor bank is suddenly released in a R-L-C circuit, including a forming coil to generate the forming force. The spiral coil is originally designed according to the requirements of plate forming. The capacitance and the discharge voltage are variable between 30-400 $\mu$F and 1-30 kV respectively. The power source has an inductance of 1.2 $\mu$H and resistance of 17.2 m$\Omega$ (reference [1]). In this experiment the power source is mainly adjusted at a capacity of 200 $\mu$F and a voltage of 4 Kv.
figure 1: The original installation.
2.1.2. THE DRIVER

The driver transforms the magnetic field in an upward force, has a diameter of 97 mm and consists of three layers. From below a 1 mm copper, a 1 mm bakelite and a 9 mm steel plate.

2.1.3. THE PUNCH

The punch leads the upward force of the driver to the powder. The punch is made of SKD11 (from MISUMI, Tokyo, Japan), has a diameter of 9.95 mm with a tolerance of +0.005 mm and a length of 200 mm. The punch bears two strain gages.

2.1.4. THE DIE

The die leads the punch and confines the powder. The die is like the punch made of SKD11, has a length of 50 mm, an outer diameter of 50 mm and an inner diameter of 10 mm with a tolerance of +0.005 mm.

2.1.5. THE TEFLOM PAPER

Teflon paper is used for isolation between the punch and the driver.

2.1.6. THE WORKTABLE

As worktable, where the whole installation is built on, a DIE HANDLER, model 1020, produced by UCHIYAMA MFG. CO. Tokyo, Japan, licensed by HANSFORD MFG. CORP., is used.

2.1.7. THE LUBRICANT

During the compaction test a lubricant is used between punch, die and powder. The name of the lubricant is Emralon 327, a dry film lubricant, containing PTFE. This lubricant is produced by Acheson colloid CO. The State of Michigan U.S.A.
2.2. THE TWO GAGE METHOD FOR MEASURING IMPACT-FORCE

Two strain gages are placed at 30 and 60 mm from the punch tip. With the signal of these two gages (A and B) the stress at the punch tip (C) can be calculated by using the two gage method for measuring impact force (see figure 2).

\[ \sigma_{c}(T) : \text{stress, caused by force } F(t) \text{ on the surface } c \text{ at the time } T \]

\[ \sigma_{cr}(T) : \text{stress wave from the right side on the surface } c \text{ at the time } T \]

\[ \sigma_{cl}(T) : \text{stress wave starting from the tip to the right side at the time } T \]

Assumption:
stress reduction ignored

figure 2: Two-gage method for measuring impact force.
\[ c = \sqrt{\frac{E}{\rho}} \] = velocity of elastic wave
\[ t_1 = \frac{1}{c} \]

\[ \sigma_e(T) = \sigma_{\text{rt}}(T) + \sigma_{\text{al}}(T) \] (1)

\[ \sigma_e(T) = \sigma_{\text{rt}}(T-t_1) + \sigma_{\text{al}}(T+t_1) \] (2)

\[ \sigma_b(T) = \sigma_{\text{rt}}(T-t_1) + \sigma_{\text{al}}(T+t_1) \] (3)

(2) and (3) gives:

\[ \sigma_e(T) + \sigma_b(T) = \sigma_{\text{rt}}(T-t_1) + \sigma_{\text{al}}(T+t_1) + \sigma_{\text{al}}(T-t_1) + \sigma_{\text{al}}(T+t_1) \]
\[ = \sigma_{\text{rt}}(T-t_1) + \sigma_{\text{al}}(T+t_1) \] (4)

\[ \sigma_e(T) = \sigma_{\text{rt}}(T-t_1) - \sigma_b(T) + \sigma_{\text{al}}(T+t_1) \] (5)

2.3. DATA PROCESSING

The signal of the strain gage bridges goes via an amplifier and oscilloscope to a computer where a program (see chapter 3.4.2) is used to calculate the stress at the punch tip by using equation 5 and stores these data on floppy disc. To recover the 'stain-data' out of the 'mV-data' from the oscilloscope, the results of a gage calibration test are used. The results of this calibration are shown in figure 3. The time-interval of the oscilloscope is from 0-4000 μs. After operation the values of 3200 μs, from the hit, at 400 μs, until 3600 μs are stored.
Calibration of gage-couple A

\[ F = -1.5491x + 6.2485 \times 10^{-6}x^2 - 6.9902 \times 10^{-9}x^3 \]

Calibration of gage-couple B

\[ F = -1.5454x + 8.4376 \times 10^{-6}x^2 - 5.0028 \times 10^{-9}x^3 \]

**figure 3:** Results of the gage calibration.
3. NOISE

3.1. ELECTROMAGNETIC INFLUENCE

The biggest problem with the installation is the enormous influence of the electromagnetic field, produced by the coil, on the signal of the strain gages. The cause of this false strain, called noise, is the magnetic field, causing a change in resistance of the element (magnetoresistive effect) and, hence a false strain signal. The magnitude of the false strain, which will be induced in a given gage depends upon the strength of the magnetic field, the state of strain in the element and the orientation of the element in the magnetic field (reference [2]).

3.2. MEASUREMENT OF THE NOISE

To measure the noise an installation as shown in figure 4 is used. The force of the driver is absorbed by the bakelite blocks in stead of the punch. The foam is placed between the punch and the driver to eliminate the influence of vibrations. The signal which is left, when the force is absorbed by the bakelite blocks is the noise. An example of three noise samples, taken with this installation, is given in figure 5. The maximum value of the noise data is more then twice as big as the maximum of the signal caused by a strong hit with a hammer on the punch. Besides, it appears that the wave shape is different in every sample.

3.3. REDUCTION OF THE NOISE

Normally the magnetoresistance effect of the active gage on a ferromagnetic sample is cancelled out by that of a dummy gage, but in this case the magnetoresistance effect of both gages is too large to be compensated. The error is due to the difference of magnetic fields which act on the gage and dummy-gage (reference [3]). Because there is not much literature about this subject, the only chance to solve this problem was to find a better installation by doing a lot of experiments.
figure 4: Installation to measure the noise.
figure 5: Three independently taken noise samples, installation as showed in fig. 3
The biggest improvements were made by:

* twining the two gage-wires, to reduce the antenna effect.
* covering the upper side of the coil with a grounded aluminium plate (diameter 140 mm, thickness 50 mm), to restrict the magnetic field.
* covering both, the coil and the aluminium plate with a grounded metal net, to restrict the magnetic field in vertical, but also horizontal direction.

By using these adjustments the maximum noise value is reduced, but still to big to ignore. More important however, is that the wave shape and -value are constant now. An example of three noise samples, after execution of these three adjustments, is given in figure 6.

3.4. REMOVAL OF THE NOISE BY USING A COMPUTER-PROGRAM

3.4.1. BASIC IDEA

Now that the signal of the noise is constant of value and shape, it is possible to remove the noise out of the signal, after doing the experiment, by using a computer. First we do a compaction test and store the signal data including the noise, then we measure the noise with an installation as in fig. 4 and store the noise data only, so that, with a simple calculation, we obtain the data of a purified signal without the noise.

3.4.2. THE COMPUTER PROGRAM

The program is written in Basic and showed in the appendix. It can be globally divided in eleven parts.

1. lines 1-1160 Starting up the program and definition and dimensioning of constants and variables.

2. lines 1170-1425 Reading of the compaction data (including the noise) of gage A and B. RS-232C is a oscilloscope button, which starts transporting the data.
figure 6: Three independently taken noise samples, after execution of the three adjustments.
3. lines 1426-1437 Converting the data received from the oscilloscope back into "mV-data" and makes the start value zero.

4. lines 1438+5010 Handling about wether to use new noise data or the old.

5. lines 4000-4425 Reading of the noise data of gage A and B.

6. lines 4426-4437 Converting the noise data back into "mV-data" and makes the start value zero.

7. lines 4440-4480 Removing the noise out of the signal by drawing the noise data from the compaction data, which results in the data of a purified signal.

8. lines 1439-1478 Converting the "mV-data" into "Pascal-data" by using the results of the gage-calibration (see figure 3*)

*) These are the results of the calibration of the "4-gage-punch", to be mentioned in paragraph 4.2.

9. lines 3000-3380 Calculation of the dynamic stress at the punch tip by using the two gage method for measuring impact force, as mentioned in paragraph 2.2.

The value 400 in line 3310 is the value of the pre-trigger setting of the oscilloscope.

10. lines 3450-3550 Storing the data of gage A and B and the dynamic stress on floppy disc.

11. lines 5000-5040 End of the program.
The results obtained with this method are shown in figure 7. In this stage of the research the test was still executed without powder. So, fig. 7A is the result of an experiment with an installation as in fig. 8, fig 7B is the result of an experiment of the installation of fig. 4 and fig. 7C is the result of the calculation of the computer.

4. BENDING

4.1. BENDING OF THE PUNCH

The frequency of the sinus wave in figure 7, purified signal, is too small to be a result of strain caused by pressure. After some simple experiments, a lateral hit gave the same frequency, it appeared to be the consequence of bending of the punch.

The influence of bending can be eliminated by the use of two couples of two-gage arrangements.

4.2. THE TWO-GAGE ARRANGEMENT

In the two-gage arrangement, strain gages are provided on two bridge-arms, and resistors on the other two arms of the gage-bridge. There are two types: active-dummy method and active-active method. In the former type, one gage is an active gage and the other is a dummy-gage; in the latter type, two active-gages are used. The active-active method is mainly used for decomposing a composite strain condition into simple strain. The composition of the bridge circuit differs depending on the analyzed strain (reference [4]).

For this experiment a type of the two-gage arrangement is chosen, very useful for measuring the simple strain alone in a composite condition of bending and simple strains. (see figure 9) It also provides an output twice as high as that with the one-gage arrangement, but temperature compensation is impossible on its circuit. Self temperature-compensating gages must be used for this purpose.
figure 7: Results of removing the noise by computer program.
figure 8: Installation without the powder, but with the three adjustments.
4.3 RESULTS WITH THE TWO-GAGE ARRANGEMENT

The results of a test with a couple of two-gage arrangements, but still without powder, are shown in figure 10. The influence of bending has decreased a lot. In figure 10c the calculated stress at the punch tip is also printed (light coloured line).

5. THE FINAL INSTALLATION

The final installation is as shown in figure 11. Alas a new problem shows up while doing a compaction test with powder in stead of blocking the punch with the frame. Because of the compression of the powder, the punch, driver, net and aluminium plate move about 1 cm upwards. Owing to this the magnetic field changes and is not equal to the situation in case of blocking the driver with bakelite blocks. If you use the method like it is developed up to now, there will still be a false strain in about the first 400 μs.

6. CONCLUSION AND RECOMMENDATIONS

Some big improvements are made. The computer program works, the punch with four gages is much better then the punch with two gages and the noise is a little bit under control.
figure 10: Results with '4-gage punch'.

10C) Measured compaction stress noise
figure 11: The final installation.
The coil, covered with a grounded aluminium plate and metal net.

The final installation.
In spite of these corrections the influence of the noise is still too big. The situations during the powder compaction and while measuring the noise differ too much, because of the difference of deformation of the blocks and on the other hand the punch and de Al-Li powder. The development of an installation to measure the noise which is closer to the situation in case of real powder compaction would be a big improvement.

Other possibilities are to do more research on noise reduction, strain gages and strain gage wires.

However the main question is: "Why using the electromagnetic device instead of a conventional mechanical one?", because the disadvantage, the noise problem, is much bigger then the advantage of an easy force adjustment.

With a mechanical installation, the four-gage punch and this computer program, except the 'noise part', I expect very good results.
REFERENCES


APPENDIX

1 'save "Yys¥save.bas",a
1000'
1010 OPTION BASE 0
1020 MODE=1
1030 SCREEN 0,0:WIDTH 80,25:CONSOLE 1,23,0,1:CLS 3
1032 LINE(0,0)-(385,8),1,BF:LINE(385,0)-(600,8),1,BF
1033 LINE(0,193)-(600,200),1,BF
1034 LOCATE 49,0 :PRINT"DATA TRANSPORTING PROGRAM"
1035 LOCATE 6,10 :PRINT"INPUT THE NUMBER OF THE BAR USED"
1040 QW$=INPUT$(1):QW=VAL(QW$)
1050 IF QW>4 OR QW<1 THEN 1045
1060 ON QW GOTO 1107,1080,1090,1100
1080 GCA=1000/55.2:GOTO 1105 :'not used
1090 GCA=1000/54.4:GOTO 1105 :'not used
1100 GCA=1000/53.7
1107 DI=10 :'punch-diameter
1110 QT=10/2000 :'oscilloscope-constant (not used see 1436)
1120 DO=3.1415*DI^2/4 :'punch-surface-area
1150 DIM RA(4000),RB(4000),NA(4000),NB(4000)
1151 DIM CA(4000),CB(4000),NA(4000)
1160 CLS 3
1170 LOCATE 25,10 :PRINT " READING THE DATA"
1172 PRINT:"PRINT" FIRST THE COMPACTION-DATA"
1175 LOCATE 15,14 :PRINT "CHANGE THE CHANNEL TO A AND PUSH THE KEY RS - 2 3 2 C "
1180 OPEN "com1:07inn" AS #1 :LOCATE 5,1
1190 INPUT #1,I$:PRINT "IDENTIFIER=";I$,"Gage No.";QW
1200 PRINT "---------- CHANNEL A ------"
1210 CONSOLE 4,22,0,1
1220 FOR I=0 TO 4000
1230 A$=INPUT$(5,#I)
1240 NA(I)=VAL(A$)
1250 PRINT "No.";I,NA(I)
1260 NEXT I
1270 CLOSE
1275 CLS 3
1280 CONSOLE 0,25:CLS:LOCATE 5,5
1290 PRINT " FINISHED READING DATA ON CHANNEL A "
1300 PRINT

A.1
1310 PRINT "CHANGE THE CHANNEL TO B"
1320 PRINT: PRINT: PRINT "AFTER DOING THIS, PUSH RETURN KEY"
1330 IF INKEY$=CHR$(13) THEN 1340 ELSE 1330
1350 OPEN "com1\071nn" AS #1
1360 INPUT #1, I$: PRINT "IDENTIFYER="; I$, "Gage Na"; QW
1370 PRINT "------- CHANNEL B -------": CONSOLE 4, 22
1380 FOR I = 0 TO 4000
1390 B$ = INPUT$(5, #1)
1400 NB(I) = VAL(B$)
1410 PRINT "No."; I, NB(I)
1420 NEXT I
1425 CLOSE
1428 PRINT: PRINT "converting compaction-data into nV"
1427 AP = 0: BP = 0
1430 FOR I = 11 TO 100
1432 AP = AP + NA(I): BP = BP + NB(I)
1433 NEXT I
1434 AO = AP / 90: BO = BP / 90
1435 FOR I = 0 TO 4000
1436 NA(I) = -5*A0 + 3*(NA(I)): NB(I) = -5*B0 + 5*(NB(I)): ' calibration oscilloscope
1437 NEXT I
1438 IF CH = 1 THEN GOTO 1440 ELSE GOTO 4000
3008 PRINT:PRINT:PRINT" calculating the dynamic stress"

3010 FOR I=0 TO 4000
3020 CA(I)=NA(I):CB(I)=NB(I)
3030 NEXT I
3310 KK=400 ; pre-trigger setting, 20 extra to ignore peek values
3320 FOR I=0 TO 4000-12-KK-20
3330 NA(I)=CA(I+KK+20)
3340 NB(I)=CB(I+KK+20)
3350 NNA(I)=CA(I-6+KK+20)-CB(I+KK+20)+CA(I+6+KK+20)
3360 NEXT I
3450 PRINT:PRINT:PRINT" Now storing the data"

3460 OPEN "b:\data.dat" AS #1
3470 PRINT #1,USING " @ @ @ @ @ @ ";"time";"gauge a";"dynam"
3500 FOR I=1 TO 3200
3510 PRINT #1,USING "#########";I;NA(I);NNA(I);NB(I)
3520 NEXT I
3530 CLOSE #1
3550 GOTO 3300
4000 ' noise recording
4010 CLS 2
4170 LOCATE 25,9 :PRINT " READING THE DATA"
4172 PRINT:PRINT" NOW THE NOISE-DATA"
4175 LOCATE 15,13 :PRINT "CHANGE THE CHANNEL TO A AND PUSH THE KEYS - 2 3 2 C"
4180 OPEN "coal:07inn" AS #1:LOCATE 5,1
4190 INPUT #1,I$:PRINT "IDENTIFIRE=";I$;"Gage No.";Q$%
4200 PRINT "-------- CHANNEL A -------"
4210 CONSOLE 4,22,0,1
4220 FOR I=0 TO 4000
4230 A$=INPUT$(5,#1)
4240 RA(I)=VAL(A$)
4250 PRINT "No.";I,RA(I)
4260 NEXT I
4270 CLOSE
4275 CLS 3
4280 CONSOLE 0,25:CLS:LOCATE 5,5
4290 PRINT " FINISHED READING DATA ON CHANNEL A "
4310 PRINT:PRINT " ② CHANGE THE CHANNEL TO B "
4320 PRINT:PRINT:PRINT "AFTER DOING THIS, PUSH RETURN-KEY"
4330 IF INKEY$=CHR$(13) THEN 4340 ELSE 4330
4350 OPEN "con1:071nn" AS #1
4360 INPUT #1,I$:PRINT "IDENTIFIRE=";I$,"Gage No";QW
4370 PRINT "-------- CHANNEL B --------";CONSOLE 4,22
4380 FOR I=0 TO 4000
4390 B$=INPUT$(5,#1)
4400 RB(I)=VAL(B$)
4410 PRINT "No.";I,RB(I)
4420 NEXT I
4425 CLOSE
4426 PRINT:PRINT"></text>
4427 PA=0:PB=0
4430 FOR I=11 TO 100
4432 PA=PA+RA(I):PB=PB+RB(I)
4433 NEXT I
4434 OA=PA/90:O=PB/90
4435 FOR I=0 TO 4000
4436 RA(I)=-5*OA+5*(RA(I)):RB(I)=-5*OB+5*(RB(I)):'calibration oscilloscope'
4437 NEXT I
4438 'removal from the noise out of the signal
4439 PRINT:PRINT:PRINT"
4440 FOR I = 0 TO 4000
4440 NA(I)=NA(I)-RA(I):NB(I)=NB(I)-RB(I)
4447 NEXT I
4448 GOTO 1439
5000 CLS 3:LOCATE 20,10:PRINT "FINISHED"
5010 INPUT"
5020 IF K$="n" THEN RUN
5030 OH=1:GOTO 1160
5040 END