SECTION B

HIGH SPEED COINING

CHAPTER 5

HIGH SPEED COINING

5.1 Introduction

The final stage of the coin production process is the coining of the blanks. To properly evaluate the quality of the coining dies and the blanks, it is necessary to coin the blanks with the dies. The coining of the blanks is done on high speed coining presses, capable of producing coins at a rate of 750 per minute. The actual deformation of the blank to produce a coin occurs in less than 15 milliseconds at this coining rate.

The coining tests will concentrate on evaluating the behaviour of the coining dies and the blanks during the coining process. The effect of blank hardness on coining results and the annealing process will receive attention in this section. The test procedure for all the coining tests was the same. The design depths of the coining dies differed for each test according to the test objectives. The coining dies were manufactured according to current specifications. A drawing of the coining die is included in Appendix C. The same collar was used for all the tests.

5.2 Test 5: 1st Coining Test

5.2.1 PURPOSE

The purpose of Test 5 was to evaluate the progressive coining of the blanks. It is easier to identify the cause of a specific coining defect, as well as to visualize how the material flows during coining when a progressive coining test is done. The dome size can for example then be altered to control the flow of the material. The detail depths can also be modified to prevent a specific coining defect.

5.2.2 PROCEDURE

The coining test was done by gradually increasing the coining force from zero to the test maximum. Samples were taken during the test, starting at 10 kN and at subsequent 10 kN intervals. The coining tests were done on a Grabener high-speed coining press. The same press was used throughout the coining tests, to ensure consistency.

The detail specifications for the first set of coining dies were as follows:

Design depth: 80 microns

Lettering depth: 70 microns

Landing depth: 160 microns

Dome height: 60 microns

The detail depths, are average depths for coins with a diameter of about 20 mm.

Normally the depth of the landing is slightly more than the depth of the design. This ensures that the coin will not spin if it is rotated on a flat surface. If the coin spins it means that the centre of the design is higher than the landing. For this test the landing depth was much greater than the design depth. Normally the landing is one of the critical areas in the design. Coining defects often occur in the landing because the landing is on the outer edge of the design. To encourage these defects the landing was modeled relatively deep.

5.2.3 RESULTS

The results of the coining test are shown in Figure 5.1. The obverse and reverse of the coin revealed similar coining patterns. At 10 kN coining force the coins show that the dies were not perfectly parallel during coining since the detail start to coin on the right hand side but not on the left. The error is relatively small in this case but care should be taken in this regard to ensure that the dies are parallel during the production process. Premature die failure can occur due to the misalignment of the dies and due to a subsequent stress concentration that is present on the one side of the dies.

The criteria for approving a coin through visual inspection are a rather vague subject. The evaluation of the detail often depends on the requirements of the client. There is no formal specification by which the detail is evaluated. The S.A Mint has a very high visual quality standard. Evaluating the process capabilities through previous products has set this standard. To complicate matters this quality standard is continually rising because of increasing competitiveness across the world. A visual inspection involves a check for the following defects: Water stains, Material deviations, Colour, Oil stains, Coining defects, Die cracks and scratch marks.

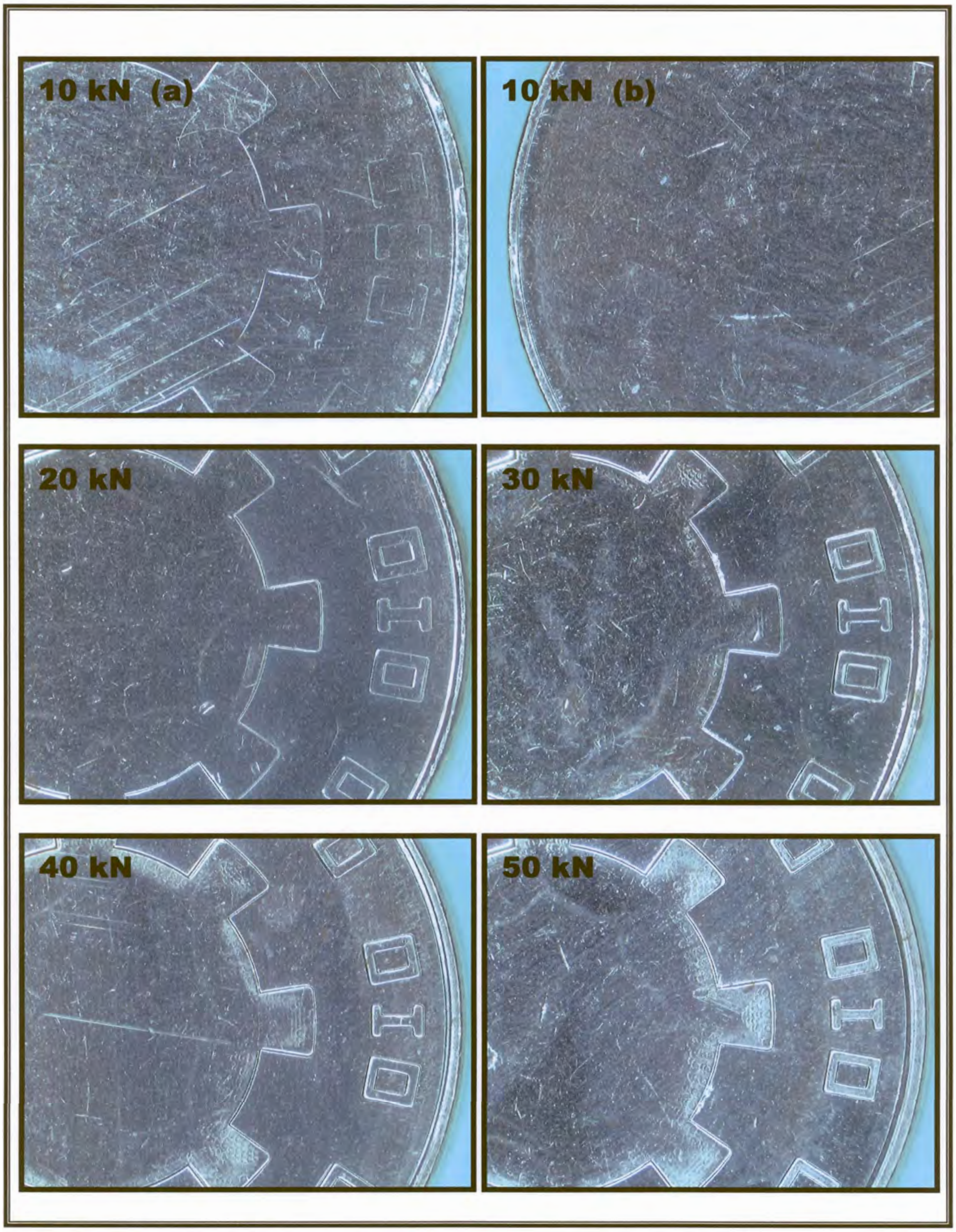

FIGURE 5.1 Coining test results. Coining force shown on each picture

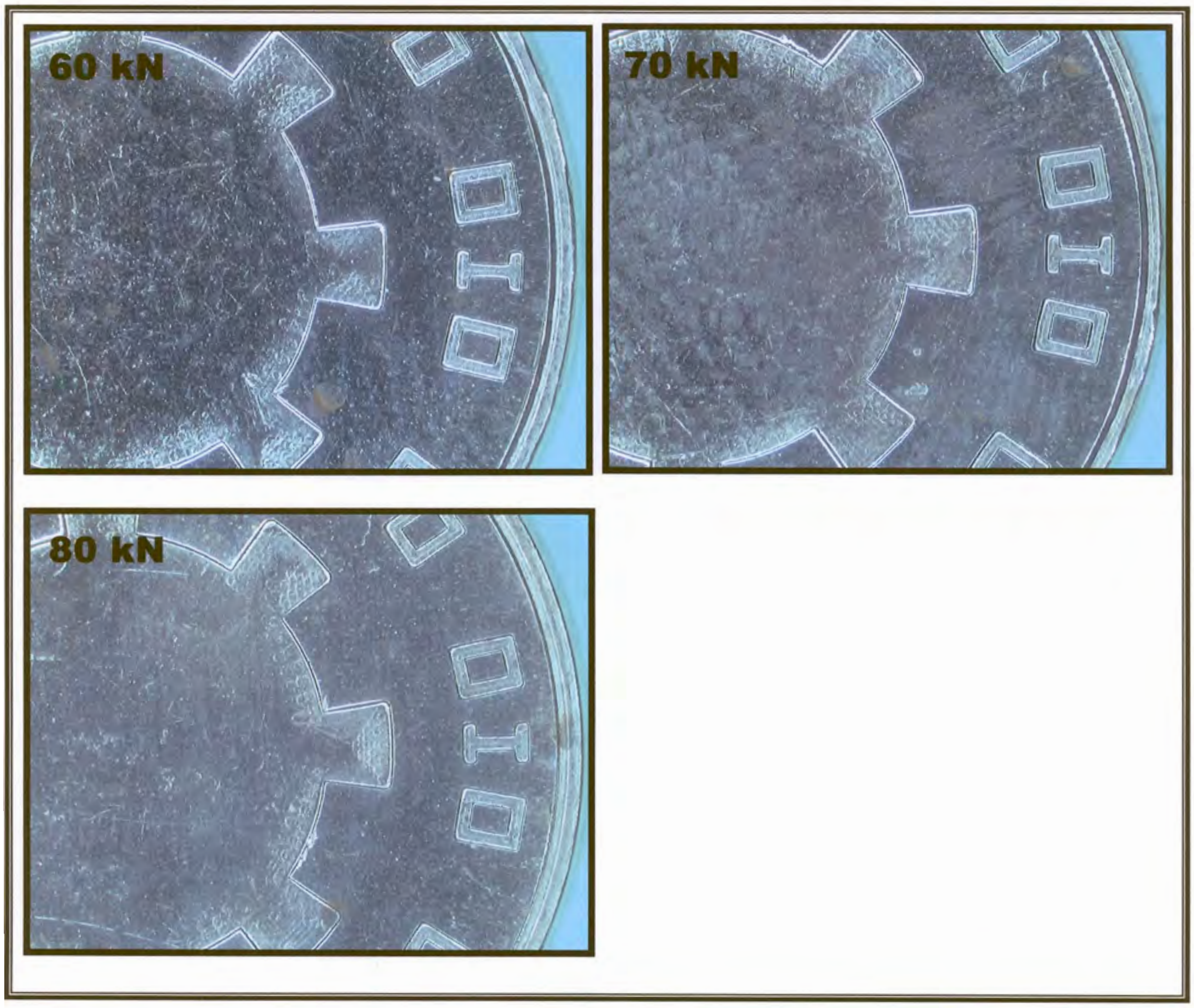

FIGURE 5.1 cont. Coining test results

The visual inspection for the products of this project will predominantly concentrate on coining defects and the evaluation of the detail transferred onto the coin. The detail is mainly evaluated according to the presence of fine detail and the sharpness of the detail transferred.

The hardness of the blanks was measured prior to coinage. 40 Samples were taken for this test. The hardness of the blanks was consistently between 100 H_v and 105 H_v. 1% of the blanks had a hardness between 130 H_v and 140 H_v. Such a large difference in hardness can cause serious problems during coining. If a hard blank is coined, the dies could fail due to the increased force required to coin the blank. To prevent such a difference, the blanks should be distributed evenly in the annealing furnace. The distribution of the blanks on the annealing furnace belt is not done properly. More distribution of the blanks on the belt is required. Foreign blanks should be prevented from entering the system and the coining press should be thoroughly cleaned if there is a denomination coining change as these blanks can cause serious damaged to the coining dies.

The progressive coining of the blanks was evaluated and it was seen that a coining force of 50 kN and higher produced coins with acceptable sharpness. Small improvements can be seen in the sharpness of the lettering and design edges for coining forces higher than 50 kN. The presence of milling marks on the coin is a sign of high quality detail transfer.

5.2.4 CONCLUSION

The sharpness of the detail is greatly influenced by the sharpness of the coalescence between different planes. The coining force is directly related to the sharpness of the detail. Due to the increasing standard in visual sharpness it is necessary to discover and investigate new ways to lower the coining force required to produce a certain amount of detail on the coin.

The coining force should also be kept as low as possible to prevent plastic deformation of the coining dies. Excessive coining forces can permanently deform the dies or it could cause the dies to crack. Lower coining forces will drastically increase die life. The most significant method of reducing the coining force and increasing die life is by reducing the hardness of the blanks. This aspect will receive attention during tests 6 and 7.

5.3 Test 6: 2nd Coining Test

5.3.1 PURPOSE

The purpose of Test 6 was to evaluate the progressive coining of the blanks with coining dies that has a deep design. Soft blanks will be tested and the results will be compared to the results of the normal blanks.

5.3.2 PROCEDURE

The procedure for conducting the test was similar to the procedure followed during Test 5. The detail specifications for the coining dies were as follows:

Design depth:	105 microns
Lettering depth:	135 microns
Landing depth:	185 microns
Dome height:	40 microns

The detail depths are very deep for a coin of this size. The landing was once again modeled relatively deep. More coining defects will be observed during this test because much more plastic flow of the blank is necessary to fill the coining die cavities.

5.3.3 RESULTS

The results obtained during the coining test are shown in Figure 5.2. The coining force that was applied is shown in the upper left hand corner of each picture. The coining dies were laser marked in the centre of the design during the manufacturing process. These markings can be seen on the coins, that were struck with a coining force of 60 kN and higher. This is a sign of high detail transfer.

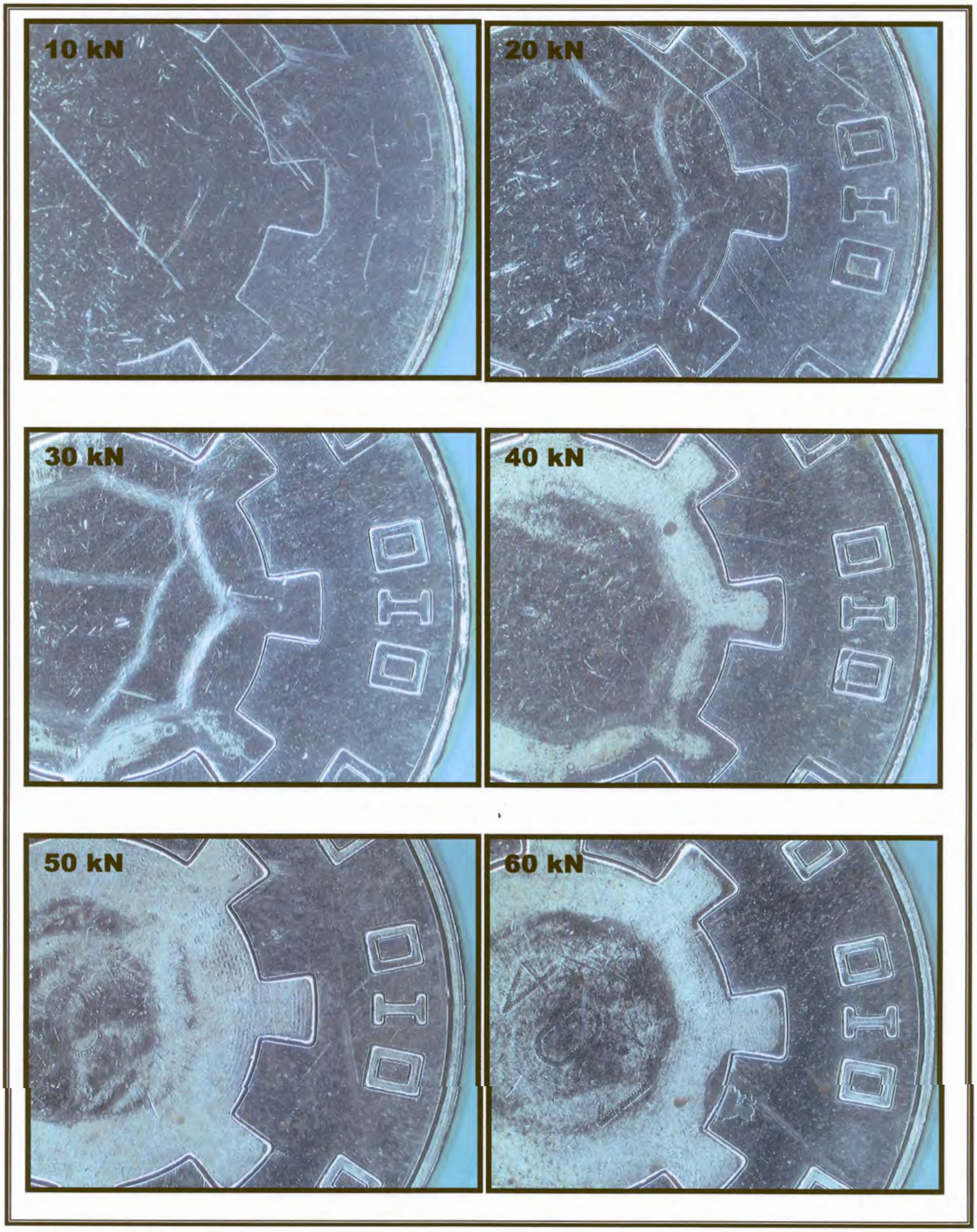

FIGURE 5.2 Coining test results.

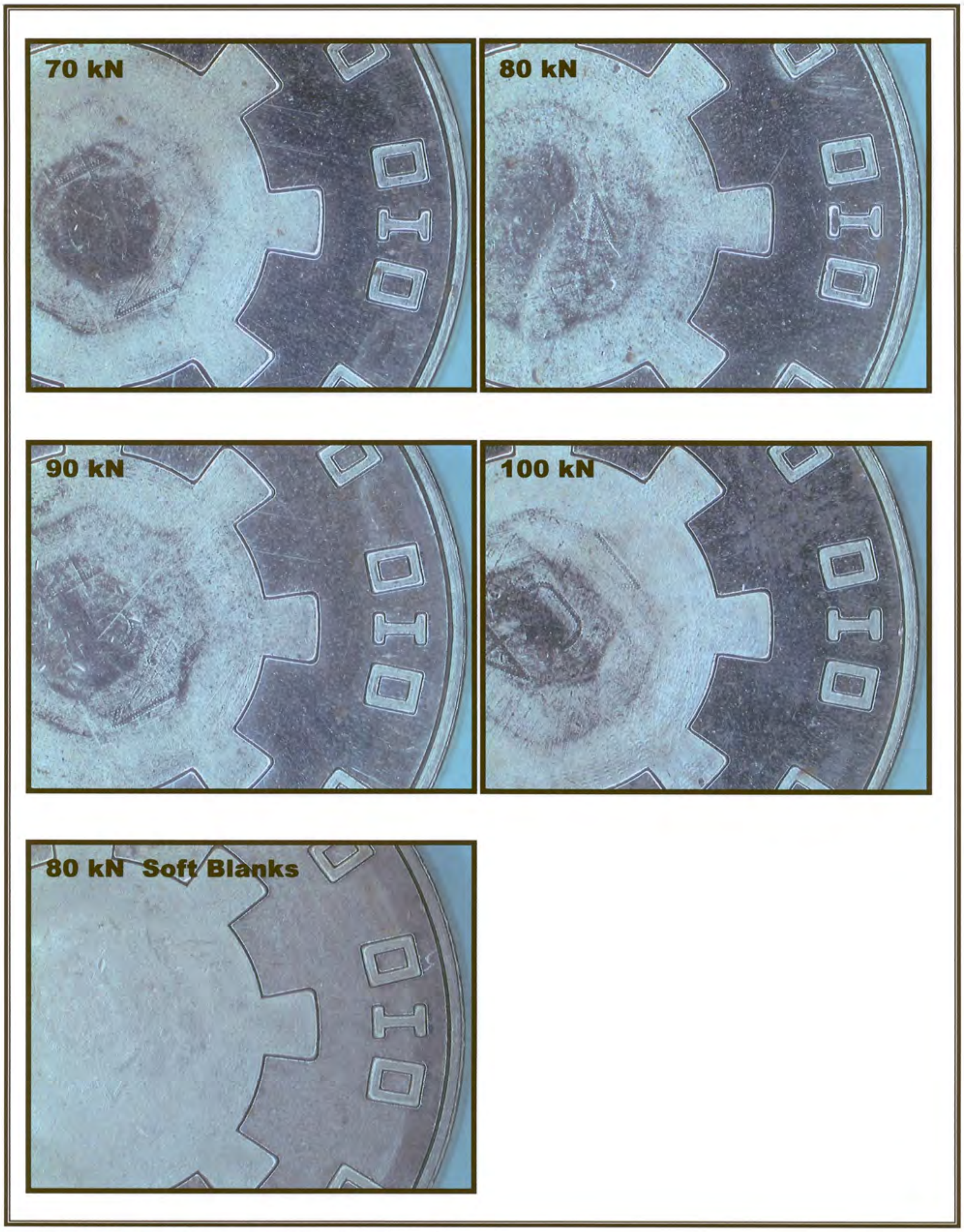

FIGURE 5.2 cont. **Coining test results**

At a coining load of 20 kN a wave is formed by material that flows from the outer edge of the design to the centre. This wave is created because there is not enough material in the centre of the blank to fill the die cavities. An increase in the sharpness of the design and lettering can be seen for increasing loads. The plastic deformation of the blank causes the dislocation density of the material to increase rapidly. The dislocation mobility decrease significantly and further plastic deformation becomes increasingly more difficult. The increased resistance to plastic deformation is called strain hardening. The yield strength of the blank increases dramatically and a further increase in the coining force can then cause the dies to fail. Due to strain hardening the wave that was created stops and the material starvation in the centre of the design cannot be completely removed, even at a coining load of 100 kN.

The hardness of the blanks was between 100 H_v and 105 H_V. A separate batch of blanks was annealed at a higher temperature to a hardness of 90 H_V. The softer blanks produced significant improvements in the sharpness of the design. At a coining load of 80 kN there was no sign of material starvation in the centre of the design and the sharpness of the design and the lettering is much better compared with the normal blanks coined at a load of 100 kN.

5.3.4 CONCLUSION

Increasing the dome height can reduce the material starvation that was observed in the centre of the design. This will be done during Test 7. It is important to note that a decrease of 10 H_v in the hardness of the blanks produced much better results. Due to the amount of strain hardening that occurred in the normal blanks excessive coining force will not improve the quality of the coins but will only lead to die failure.

5.4 Test 7: 3rd Coining Test

5.4.1 PURPOSE

The purpose of Test 7 was the same as Test 6. A few modifications were made to the coining dies for this test. Normal blanks as well as soft blanks were used during this coining test.

5.4.2 PROCEDURE

The procedure for conducting the test was similar to the procedure described for Test 5. The detail specifications for the coining dies were as follows:

Design depth: 100 microns
Lettering depth: 130 microns
Landing depth: 145 microns
Dome height: 90 microns

The landing height was decreased by 40 microns and the dome height was increase by 50 microns for this test. The increase in dome height will promote the coining of the design in the centre of the coin thereby reducing the amount of material starvation. Because the landing depth was reduced, slightly more material will be available to fill the remaining detail cavities. The same blanks were used for this test as was for Test 6.

5.4.3 RESULTS

The results obtained during the coining test are shown in Figure 5.3. The coining force that was applied is shown in the upper left hand corner of each picture.

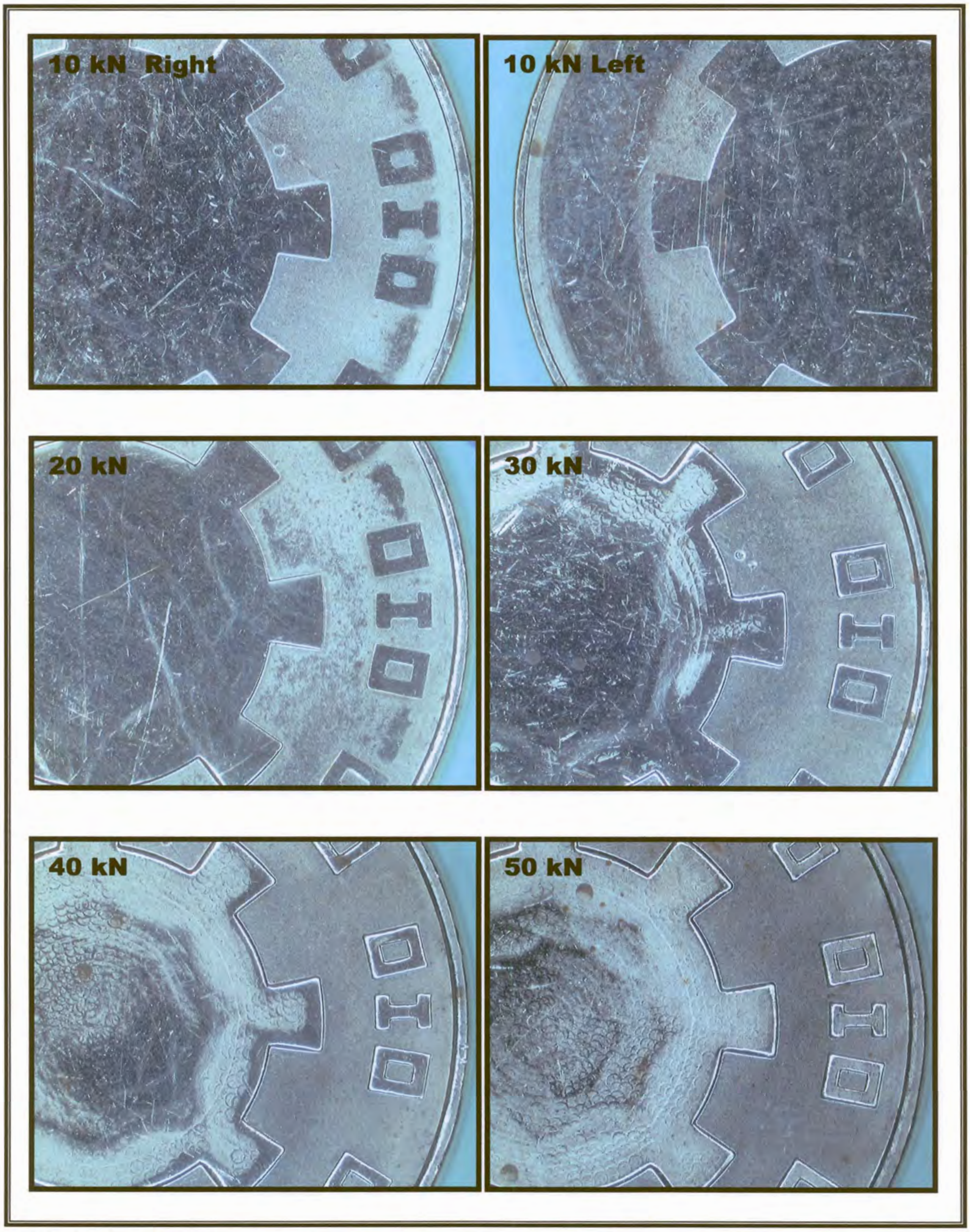

FIGURE 5.3 Coining test results. The coining load is shown on each picture.

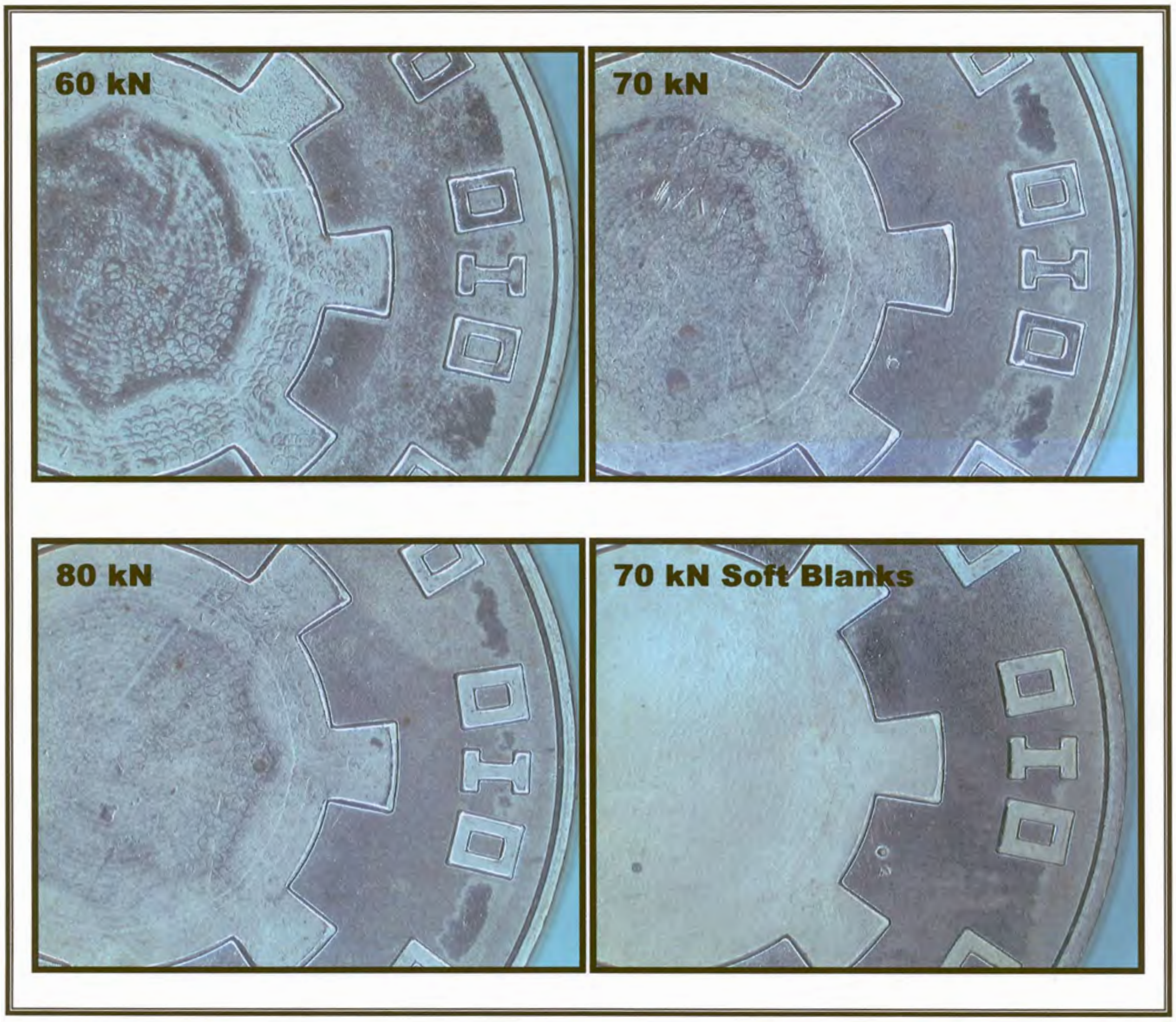

FIGURE 5.10 cont. Coining test results

At a coining load of 10 kN the misalignment of the dies can be seen. The lettering starts to coin on the right hand side of the coin but not on the left. The wave of material flow that was present in Test 6 can still be seen but it is much less. As expected the increase in dome size produced better coining results in the centre of the coin but the sharpness of the lettering and the edges of the design decreased. Once again much more detail was transferred to the soft blank.

During the final rolling of the steel sheets the hardness of the material increased from 100 H_v to above 200 H_v due to strain hardening. The amount of strain hardening that occurs, depends on the percentage reduction in thickness during the rolling process.

The coinability of the blanks is highly dependant on the hardness of the blanks prior to coining. Significant improvements can be obtained during coining by reducing the hardness of the blanks as was seen during the coining tests. This can be done in several ways. One method of reducing the hardness of the blank is by increasing the temperature of the annealing process. This can only be done to a certain extent since the plating layer forms bubbles if the annealing temperature is too high. The furnace belt speed can also be decreased, thereby increasing the annealing time.

Alternatively the blank material can thoroughly be annealed after final rolling and before blanking or after blanking and before plating. By annealing the material before blanking the amount of wear on the rim block and marking ring is reduced. During rimming the hardness of the edge will increase due to strain hardening. This hardening will prevent creep between the collar and the die during coining.

The minimum hardness of the blanks is limited by the grain size of the blank material. A large grain size will cause the surface finish of the blank to look like an orange peel. During the annealing process the metal structure will go through a series of changes namely, (1) recovery, (2) recrystallization and (3) grain growth. During cold working a lot of the strain energy is stored in the material in the form of dislocations. During annealing the dislocations are allowed to rearrange themselves in lower energy configurations and thereby the residual stresses are released. The recovery phase is followed by a recrystallization phase where new, strain free grains are nucleated and begin to grow in the metal structure. These new grains continue to grow until the entire structure is replaced by a recrystallized structure.

The amount of recrystallization that takes place depends on the annealing temperature and duration. During the annealing process the strength and hardness of the material is decreased while the ductility and therefore coinability of the metal is increased.

From the work of Petch [1] and Hall [2], the yield strength of a polycrystalline material could be given by,

$$\sigma_{ys} = \sigma_i + k_y d^{-1/2}$$

where σ_{ys} = yield strength of polycrystalline sample.

σ_i = overall resistance of lattice to dislocation movement.

k_y = "locking parameter" which measures relative hardening contribution of grain boundaries.

d = grain size.

It is clear that the strength of the material is proportional to dislocation density and inversely proportional to grain size. The grain boundaries act as barriers to the movement of dislocations and a structure with a small grain size effectively has more barriers [3,4].

5.4.4 CONCLUSION

During the coining tests it was seen that for a blank hardness of 90 H_v the grain size was sufficiently low, not to have any noticeable affect on the surface finish. Further research is recommended to determine the minimum hardness of the blanks that will still provided an acceptable surface finish.

Valuable information was obtained during the coining tests. The use of progressive coining tests, as described in this chapter, are recommended for all development projects. Information was obtained by means of this test method that would otherwise not have been possible. It is easy to see which part of the design starts to coin first and which areas have difficulty in coining properly. Modifications can now be made to the design to improve the coinability of the blanks.

5.5 Calibration of High Speed Coining Press

5.5.1 INTRODUCTION

The coining presses that are in use at the S.A Mint gives a digital readout of the applied force during coining. These presses should be calibrated to ensure that all the presses give the same readout for a certain applied force. The coining force necessary to produce coins for a specific denomination can then be compared to the results obtained through previous coining operations. By calibrating the presses a baseline is established and deviations in the coining force can easily be detected.

Ideally the coining presses should be calibrated to give an accurate reading of the coining force. The manufacturer of the coining press should do the calibration or the task should be outsourced to a company with the required capabilities. This may prove to be difficult and expensive, therefore an alternative procedure will be suggested whereby the coining presses can be calibrated.

5.5.2 PROCEDURE

It is not crucial that the coining presses give a very accurate reading of the applied force. What is of utmost importance is that all the presses give the same reading for a specific applied force even though it may not represent the actual applied force. A simplified procedure was developed that will enable the S.A Mint to do the calibration. The procedure is outlined below.

IMPORTANT: All tolerances on the specifications of the tooling and the material that will be used during the calibration test should be very tight to ensure accurate results during the calibration.

1. Choose blanks

To simplify the process, any existing blank design can be used. A blank design must be chosen and specified for the test. The hardness of the blanks should be specified and one should ensure that all the blanks have the same hardness. This blank design must be used for all subsequent calibrations once it has been chosen.

2. Choose design

A coining die design must be selected for the calibration procedure. An exaggerated profile of the suggested die design is shown in Figure 5.4. Any design that has a clear reference point can be used for the calibration. The detail dimensions of the die should be chosen such that the reference point starts coining at a force of about 60 or 70 kN. The evaluation criteria of the calibration coins should be clearly stated.

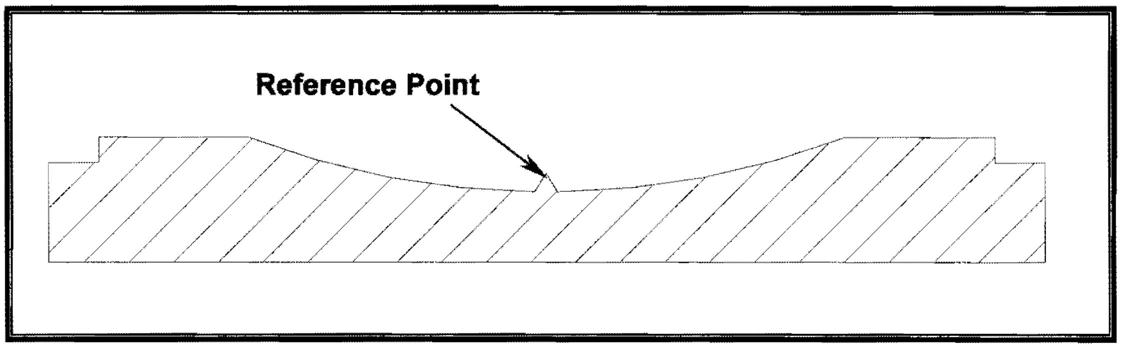

FIGURE 5.4 Calibration Die Design

3. Specify tooling sizes

This includes the diameter of the collar and the die neck.

4. Manufacture tooling

The hardness of the dies should be specified and checked. The material that will be used for the calibration dies should be specified.

A reference press is chosen and the calibration dies are used to coin the blanks at a specified speed. The coining force is gradually increased from zero. A soon as the reference mark start to coin, the applied force is noted and the coining operation is stopped. The calibration dies are then inserted into the second press and the same procedure is followed. As soon as the reference mark starts to coin the reading on the press is noted and must be adjusted to give the same reading as the reference press. This process continues until all the presses have been calibrated.

All the presses will now give the same reading for a certain applied force. This calibration should be done frequently to ensure consistency in the coining loads. If this is done it will be easier to determine the cause for coining force difference for a specific denomination. If, for example, one press coins at a higher load than the other presses a possible cause could be attributed to misalignment of the dies or to blank hardness differences.

REFERENCES

1. N.J Petch, **JISI 173,** 25 (1953)
2. E.O Hall, **Proc. Phys. Soc. B 64,** 747 (1951)
3. Richard W. Hertzberg, **Deformation and fracture Mechanics of Engineering Materials,** John Wiley & Sons Inc., p. 129 – 130, (1996)
4. William F. Smith, **Principles of Materials Science and Engineering,** McGraw-Hill, p. 290 – 296, (1990)

SECTION C

DESIGN PROTOCOL

CHAPTER 6

DESIGN PROTOCOL

6.1 Introduction

The tests that were conducted during the project revealed valuable information about the development and production process. The results and the recommendations for each test have already been discussed in the previous sections. A new design protocol will now be established using the information that was gathered during the tests. The protocol will not contain all the development and production details and it does not replace current development procedures. It should be regarded as an overview of the development process, which concentrates on certain critical development issues. Where recommendations are given the reader is referred to the relevant section in the report for a detail discussion regarding the rationale behind the recommendation.

The purpose of the design protocol is to enable the developer to achieve improved results during the development process. The design protocol can also be used as a tool to establish the cause and recourse for certain development problems. The main objective of the protocol is to improve consistency in the results that are obtained during the development process.

The design protocol will be presented in the form of a checklist and will span from the acquisition of the die and blank material to the final production of the coins. The protocol will be broken down into several sections. The heading of each section will refer to the chapter containing the relevant research material.

6.2 Design Protocol

I. Material Analysis CHAPTER 1

1. Tool Steel
   - Composition Analysis
   - Chemical Element distribution
   - Microstructure
   - Nondestructive Testing
   - Hardness Test (*Ref*: Par. 1.2.2.5)

     The hardness should be checked on all incoming material, especially the tool steel. The initial hardness of the tool steel greatly affects its behaviour during the deformation and heat treatment processes. An even hardness distribution is essential for consistent results.

2. Blank Material
   - Composition Analysis
   - Hardness Test

     The hardness of the blank material should be tested to ensure that the hardness is within the specifications.

II. Coin Design CHAPTER 2

1. CNC Engraver

- The development time is reduced dramatically if the design can be engraved on the CNC engraver. Therefore the CNC engraver software and hardware should continuously be upgraded to enhance its capabilities.

III. Blank Design CHAPTER 3

1. Development of blanks

- The blanks should be redeveloped for all denominations where coining problems occur, to ensure that all specifications are correct.
- Development of rimming profile.

  Future development should be done on the rimming profile to improve coining results. The rimming profile has a significant effect on material flow during coining.

IV. Development of Master Punch CHAPTER 4

1. Manufacturing of die blanks (*Ref*: par. 4.8)

- Manufacture die blanks with cone angle.

  Currently a cone angle of 30° is used for all the die blanks. For this project a cone angle of 35° yielded the best results regarding transfer of detail and dimensional stability. The optimal cone angle should be determined for each project by varying the cone angle and recording the results.

- Heat-treat die blanks.

  The die blanks should be annealed prior to hobbing. There are two main reasons for this. The first is to ensure an even hardness distribution between the die blanks. This will lead to greater consistency during the hobbing process. The second is to reduce the required hobbing force and to increase the amount of detail transfer. The decrease in hobbing force will reduce the amount of plastic deformation to the matrix during hobbing.

- Specify manufacturing process.

  The diameter and length of the die blanks should be specified with a close tolerance. This will improve consistency during the hobbing and heat treatment processes. The machining procedure should be specified and should remain constant.

- Collect data

  Data should be collected for all projects regarding the optimal die blank cone angle and hardness. This will improve repeatability.

2. Hobbing (*Ref*: par. 4.8)

- Hobbing alignment

  Ensure that centre of matrix is in-line with die blank point during hobbing. The die blank point must make contact with the centre of the matrix.

- Record required hobbing force and maintain that force for all subsequent hobbing processes for that specific denomination.

- Consistency of utmost importance.

3. Machine master punch.

- Machine master punch according to specifications.

  Specify concentricity of design relative to the body of the design.

  Keep machining practice constant.

- Modify shape and dimensions of master punch slots. (*Ref*: par. 4.9)

  The new slot dimensions should be specified to ensure consistency in the manufacturing process.

4. Heat treatment

- Ensure that correct temperatures are used according to the specifications.
- Avoid heat-treating objects with large size differences in one process.
- Distribute dies evenly in furnace.

  The packing of the dies and punches in the furnace has a significant effect on the dimensional stability of the dies. If the dies are packed close together the dies in the middle will experience a different cooling rate, and therefore dimensional change, than those on the outside. Ensure that the dies are spaced at equal distances apart in all directions. A template can be manufactured to ensure repeatability in the spacing distances.

- Attempt to heat-treat an equal number of dies.

  This will not always be possible but note that the amount of material in the furnace also has an effect on the cooling rate of the dies. Dummy dies can be used to make up numbers during heat treatment. These dies can be used repeatedly. The dummy dies can also be used to ensure that every die has an adjacent die on every side.

- Record dome size

The shape change of the dome size during hobbing and heat treatment will vary for every denomination. The shape change should be recorded and can then be used as an input for future development.

V. Coining CHAPTER 5

1. Blanks (*Ref*: par. 5.1 - 5.4)

- Heat-treat blanks.

The blanks should be annealed to reduce the hardness of the blanks. Softer blanks significantly improve coining results. The coining force is reduced and the detail transfer is superior to that of harder blanks. The relative importance of the dome height is also reduced if the coining force is reduced.

- Check hardness of blanks to establish hardness distribution.

2. Coining dies

- Stress concentration (*Ref*: par. 4.9)

The stress concentration present at the bottom of the die neck should be reduced by introducing a minimum fillet radius of 5 mm at this location.

- Alignment of dies

The coining dies should be aligned as parallel as possible, to reduce the high localized stresses that are set up at the edge of the die due to the skew alignment of the dies.

3. Calibration of coining presses. (*Ref*: par. 5.5)

- The coining presses should be calibrated to ensure that all the presses give the same reading for a specific applied force.
- Consistency in coining forces should be maintained.

At the end of the day a complete data sheet must be developed for all the denominations. When a specific denomination is produced, this data sheet can be obtained and used to produce repeatable results in the development and production processes.

6.3 Conclusion

The objectives of the project have been met successfully. The design protocol that has been established will allow the developer to achieve better results during the development and production of the coining dies.

The design protocol addresses the major contributing factors for successful die development. The key to successful die development lies in consistency. By improving consistency on all aspects of the development process, fewer problems will be encountered and less iteration will be required to achieve the desired results. Less iterations translates into a reduction in development time and a significant reduction in development cost.

The project concentrated on the development and production of the coining dies. Attention was given to the coining blanks but further development of the blanks is necessary since these two products are so closely related.

Further development efforts should concentrate on the reduction of the required coining force. Many of the problems that occur are problems that arise due to unnecessary high coining forces. Development of the blanks is one of the most significant ways to reduce the required coining force.

The Four Cartesian Rules:

- Never accept anything as true if you do not have objective evidence of its being so.
- Reduce each complex problem into separate parts, as many as are feasible and necessary to obtain a solution to the problem.
- Obtain a solution through ordered sequence of logical steps, ascending from simple to complex, from small to large.
- Make complete enumerations throughout, so as not to overlook anything.

> If you do this, there can be nothing too remote to be reached, or too well hidden to be discovered.
>
> René Descartes (1596-1650)