SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

FINAL REPORT

Title: **EVALUATION AND FURTHER DEVELOPMENT OF A 'QUIET' NON-ATMOSPHERIC POLLUTING BLAST HOLE DRILLING SYSTEM**

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Executive Summary

Historically drill and blast mining has been the subject of much thought and speculation over many years, all of which is inversely proportional to the actual development and progress in refining this crude method of releasing ore bodies.

The current techniques employed provide a very hostile, and potentially dangerous and damaging environment for the people involved in the extraction of these ore bodies.

This report covers the work done to address one of the contributing aspects to this harsh environment, and that is the noise emitted by the rock drill.

Whilst noise reduction remains the main thrust of this project, it was further extended to embrace the possibility of designing a Quiet Self Thrusting rock drill. The advantages of such a unit could be far reaching, resulting in the reduction of noise levels in a stope face and at the same time introducing a system that could improve productivity by very much greater accuracy in drilling and improved labour utilisation.

This project is then driven by the goal of reducing the noise levels emitted by the drills which would result in the reduction of the hearing related problems currently being experienced by the drill operators and crew in the immediate areas. These hearing problems are generally of a permanent nature and are compensated at a significant cost to the mining industry. This goal should be achieved without any reduction in current productivity levels.

The primary objective of this project is the further development and evaluation of the quiet blast-hole drilling system initially developed under project GEN 207. The main focus of this work is the resolution of the limitations and deficiencies identified in the prior work. In the previous work it was demonstrated that effective noise reduction methods existed for each of the major noise sources within a pneumatic rock drill and that these could be combined to provide a quiet blast hole drilling system provided that the thrust system produced the required thrust along the axis of drilling (ie 'in-line' thrust). In the previous work this was achieved by effectively converting the rock drill to a piston within a sealed cylinder and providing the necessary thrust pneumatically. This arrangement achieved operational noise levels of 87.5 dB during over travel and 92 dB during drilling.

Unfortunately, the use of pneumatic thrust introduced several problems relating to the control and maintenance of the required thrust. These problems generally arose from difficulties in maintaining an acceptable level of sealing in the complex sealing arrangement.

The results of the work were sufficient to warrant further development of the system and consequently this project was established. The primary focus of the work was to establish a thrust system which avoided the problems identified in previous work yet retained an 'in-line' arrangement thereby providing the features necessary for the application of the previously established noise reduction methods.

The thrust method developed was that of a reciprocating mechanism based on a standard beam crawler. Four prototypes were developed and manufactured and tested in surface drilling into Norite. The machines retained the noise reduction levels of the previous prototypes and provided drilling performance more than equal to a standard drill and leg arrangement. However, the thrust mechanisms proved to be limited in available thrust and endurance with several failures of small plastic elements within the pneumatic circuit at lives as low as 40 metres of drilling.

The problems identified during surface drilling are readily amenable to resolution with existing technology and know how and could be effectively introduced during commercialisation of the product. It is concluded that the concept as presented can provide for a quiet blast hole drilling system

In conclusion while the project achieved its objective in proving that the concept of a quiet rock drill is possible, further work is required to take the concept to full commercialisation.

Preface

Past research has shown that to a large extent, specific noise sources within blast-hole drilling systems can be individually addressed but, in general, such solutions have been found to be impracticable for underground application. In reviewing past work in this area a novel concept was identified which would enable the practical application of previously identified noise reduction methods and technologies. The basis of the concept was to integrate the rock drill and the thrust leg into one device, i.e. the drill becomes a piston within an enlarged thrust leg. This configuration not only provided an effective method of applying identified noise reduction methods, but also afforded several advantages in the operation and handling of the drilling system. The noise level of a commonly used pneumatic rock drill was reduced from 111 decibels on an A-weighted scale (dBA) to 87 dBA while running in over travel. However, subsequent evaluation of the system identified several limitations in the area of dynamic seals particularly those involved in the provision of the thrust force. These limitations were addressed by the design and implementation of a thrust system based around a pneumatic 'beam crawler'. This design afforded several benefits via an overall simplification of the system while maintaining the original performance and noise reduction levels.

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1 Introduction

According to a survey conducted by the National Institute of Occupational Safety and Health (NIOSH), the number of workers exposed to noise on the job far exceeds the number of those exposed to any other significant occupational health hazard. The nature of noise-induced hearing impairment is a painless progression of irreversible damage which is not apparent in the early stages, only becoming so when speech communication is affected.

A COMRO study (Van Rensburg, 1990) of noise levels in the gold and coal mining industries found that the noise levels for all occupations in the gold mining industry exceeded an equivalent noise exposure of 85 dB as recommended by SABS 083. In their report on occupational risk in the mining industry, Peak and Ashworth (1996) determined that although the individual risk of noise induced hearing impairment is relatively low, the total industry risk is equivalent to the risk of fatal injury accidents, or 651 equivalent years loss of life expectancy (EYLLE). While the result of such a determination may, at first sight, appear contentious the methods by which it was attained is covered in detail and appears sound and the final result may, therefore, be taken as a strong indicator of the relative importance of noise induced hearing impairment.

In the South African gold mining industry alone it is estimated that approximately 500 000 blast holes are drilled each day using 20 000 pneumatic machines with approximately 45 000 employees being directly exposed to the high levels of noise emanating from these machines. At noise levels of typically 120 dB during drilling there is a 41 percent probability of those exposed becoming compensibly deaf within five years which, at 1990 compensation levels, equates to an annual compensation cost of close to R 30 million. Recent changes in the methods for determination of compensable levels of hearing loss and changes in the rate of compensation will substantially increase this cost . With the current increased focus on safety and the pro-active role of employee organisations it is not unlikely that without a major reduction in the exposure levels, the cost of compensation will rise. The noise produced by rock drills not only places a large number of men at risk to lost hearing, but, additionally, compromises safety in the stope by seriously inhibiting communications.

Legislation relating to noise control and hearing conservation was promulgated on 02 June 1989 in "Regulations 4.17.1-4, of the Mines and Works Act". In this Government Gazette an amendment to the regulations of Mines and Works Act stipulates that wherever the equivalent noise exposure in the work place exceeds 85 dB(A), 'the manager shall take the necessary steps to reduce the noise below this level'(Kielblock et al, 1987).

Maximum permissible sound level in any working environment in South Africa is specified, indirectly, as an operator equivalent noise exposure (Neq) which is not to exceed 85 dB irrespective of the prevailing sound pressure level. For every increase of 3 dB above the specified level the permissible employee exposure time is halved. Since typical noise levels of pneumatic rock drills are in excess of 112 dB, this relationship indicates a permissible daily exposure of less than one minute. Permissible exposure times of this order effectively preclude any drilling. However, by invoking the amendment to the Mines Act, drilling can be carried out provided that an effective hearing conservation programme is established. However, according to research conducted by COMRO (Van Rensburg, 1987) the long term objectives when dealing with drill noise problems should be directed toward noise reduction at source rather than on personal protection and administrative control.

Similarly, experience elsewhere suggests that if noise reduction techniques are considered at the design and construction stage of plant and machinery, considerable reductions in noise emissions could be derived. It is contended that most industrial noise has its origins from improper design and application of the equipment.

In recognition of this problem, the South African mining industry (in common with mining interests throughout the world), rock drill manufacturers, and other interested parties have, over the past three decades, expended considerable effort and resources into research and development programmes to reduce the noise level of blast-hole drilling systems. As a result, both the United States Bureau of Mines (USBM) and the Chamber of Mines Research Organization (COMRO) have both been active in this field. The United States Bureau of Mines (USBM) has, in particular, conducted a considerable amount of research in this field both in the laboratory and in the field In a review of this work Visnapuu and Jensen (1975) stated that the noise levels of the common pneumatic rock drills can be reduced from 115 dBA to 97 dBA by modifications which do not change the basic configuration or utility of the drill. However, a final conclusion of this work was that: 'any further noise reduction would require enclosing the complete drill and drill steel in an air bag or similar device'.

In a previous development the enclosure suggested by Visnapuu was achieved by incorporating the drill as a piston in an enlarged thrust leg tube which not only provided the required enclosure but also the thrust for drilling (Harper GS, Radzilani 1996). This configuration proved ineffective in surface testing and a revised design was produced and tested.

2 Review of previous work

2.1 Sources of noise in pneumatic rock drills

The major sources of noise associated with pneumatic rock drills (Figure 2.1.a) have been identified by many researchers. The major sources in order of magnitude are the exhaust ports, drill steel, and the drill body.

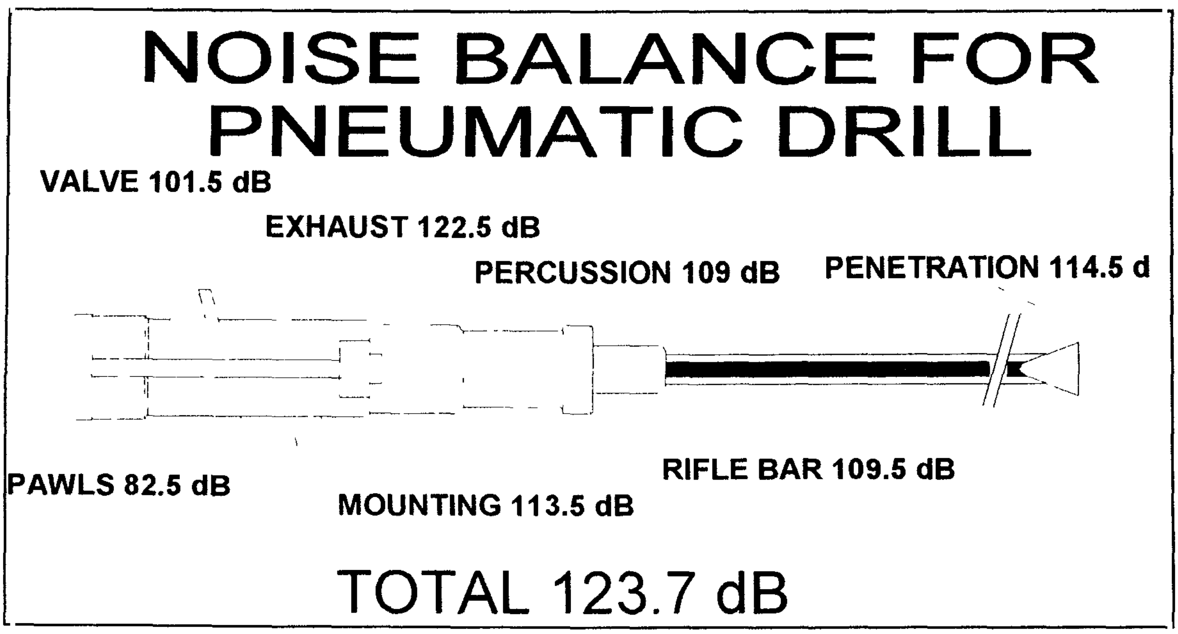

Figure 2.1.a Typical distribution of noise sources of a pneumatic rock drill

2.1.1 Exhaust Air Noise

The exhaust noise of a pneumatic rock drill has been identified as the predominant source, accounting for approximately 90 percent of all the noise emanating from a drill/drill steel combination (Beiers, 1966).Consequently most noise reduction strategies have focussed on silencing the exhaust air.

There are several methods by which the exhaust air noise level may be reduced including dissipative silencers, reactive silencers, or noise cancelling techniques. From the investigations carried out by the USBM (Chester et al., 1966), reactive exhaust silencers were found to be the most suitable for exhaust noise attenuation. For a silencer to be considered acceptable in the mining industry, the following minimum requirements have to be met:

Silencers should be small and light weight;

Back-pressure should be as low as possible, and

Silencer should be adaptable to attachment to a rock drill or incorporating into the shell of the drill itself.

The reactive silencer was found to meet the above requirements, as well as being amenable to analysis by electrical analogy simulation and, therefore, could be designed without recourse to time-consuming and expensive mechanical trial constructions. The pi-reactive silencer is simply two volumes connected by a small tube of determined impedance

The basis of the analogy (De Woody RT. 1964) derives from the fact that both acoustical and its electrical equivalent are both based on the same basic laws of conservation of energy. According to electrical and acoustical analogies, a tube with a diameter that is small in comparison to its length has the properties of series resistance and inductance, and the impedance of a small diameter tube is given by the following equation (Olsen HF 1957· 56-123):

$$Z_A = \frac{8\mu l}{\pi R^4} + j\omega \frac{4\rho l}{3\pi R^2} \tag{2.1}$$

Where R = Radius of the tube in 'cm'.

μ = Viscosity coefficient ($1.86.10^{-4}$ for Air).

ω = $2\pi f_A$ where f_A = frequency in Hz.

ρ = Air density ($1.2.10^{-3}$ g/cm3 at 20°C.)

l = Tube length, in 'cm'.

j = Square root of minus one.

This relationship is used to determine the physical dimensions of elements of the muffler from its electrical analogue.

The input parameters to the design methodology are the drill frequency, the cross-sectional area of the drill exhaust port and the selected filter cut-off frequency. The parameters selected by De Woody et al (5 cm^2 exhaust port area, drill frequency of 30 Hz and a cut off frequency of 100 Hz) were sufficiently close to those of the SECO 215 rock drill (4.8 cm^2 exhaust port area, drill frequency of 28 Hz and a cut off frequency of 100 Hz) to warrant using the same design parameters for the initial prototype. This was considered appropriate considering that the analysis assumed a constant air density and therefore does not account for changes of pressure and/or temperature within the muffler. The design parameters of the pi-reactive muffler developed by the USBM are shown in Figure 2.1.1.a.

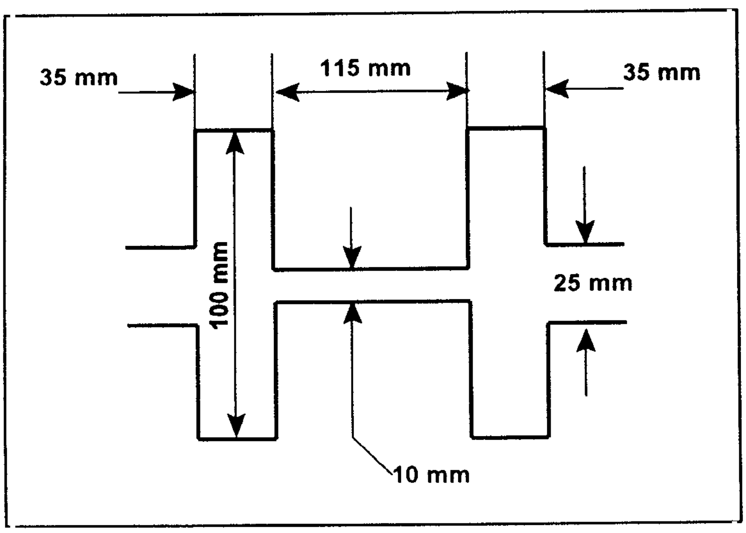

Figure 2.1.1.a. Pi-reactive muffler details (De Woody et al :1964)

A particular feature of the analysis of the pi-reactive muffler is that the geometry of the input and output volumes is not significant, provided that is, that their diameter to length ratio is sufficiently small to avoid acoustical resonance. With this feature it was possible to develop the requisite muffler geometry by cylindrical enclosures around the percussion and rotation sections of the drill with the lengths of each enclosure being modified to provide the required volume as shown in Figure 2 1.1.b.

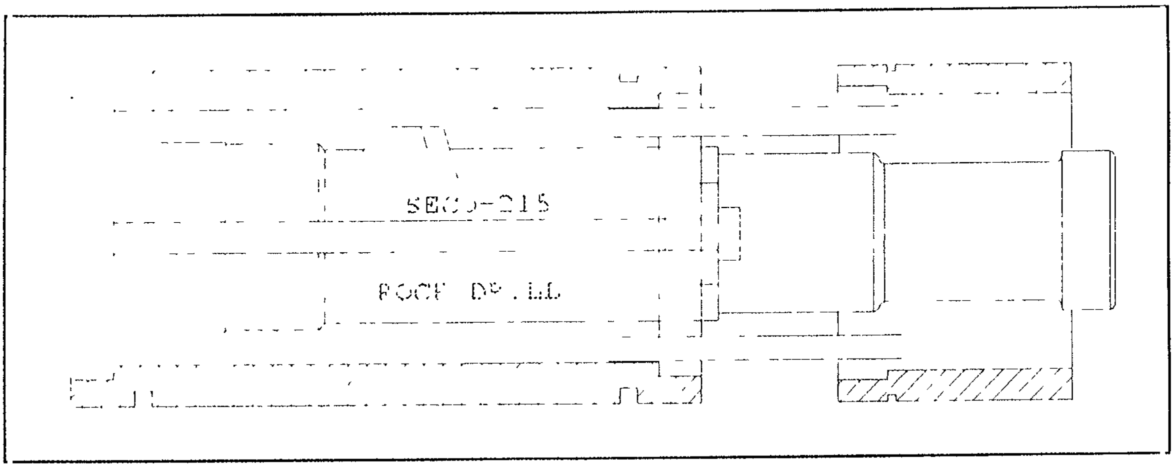

Figure 2.1.1.b Pi-reactive muffler arrangement on a SECO 215 drill

2.1.2 Drill steel noise

The ringing of drill steel after periodic impact radiates sound energy which is of equal magnitude, if not greater, to that of the drill body and approaching that of the exhaust air. A constrained-layer damping system proved to be an effective method of reducing drill steel noise.

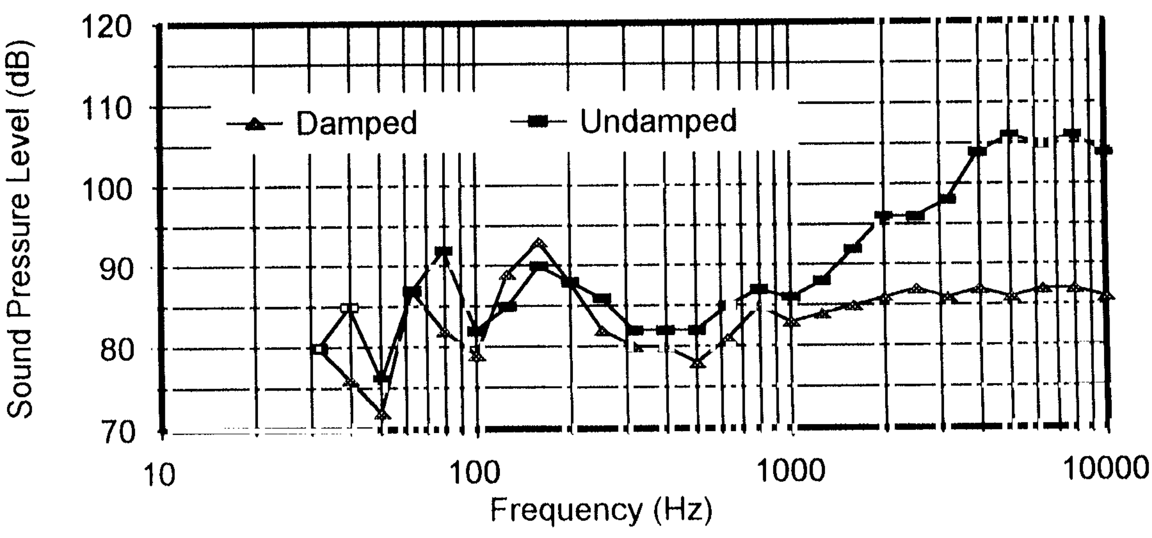

Figure 2.1.2.a Comparison between damped and undamped drill steels

This system consists of a thin walled tubular metal cover bonded to the drill steel by viscoelastic material which adheres well to both. The results of tests conducted by the USBM on constrained layer damped drill steels is shown in Figure 2.1.2.a.
In the present design, a standard 25 mm forged collar divided-bit drill steel was damped in the same fashion using a polyurethane strip as a filler and a 1,5 mm wall thickness mild steel tube. Noise emission comparisons between damped and undamped drill steels were conducted in open space and the results were such that the noise level of (plain) undamped drill steel was reduced from 108 dBA to 95 dBA. Experiments with different types of drill steels have shown a lower noise emission from divided drill steels, when compared to standard integral drill steels.

2.1.3 Noise from internal components of the drill

Other sources of noise are bit noise during collaring and rock penetration and impact noise between piston and drill steel shank. There is additional noise associated with the ratchet mechanism, the air valve oscillation, the rifle bar movement, and chuck rattle (Beiers, 1966). Percussion noise and penetration noise were found to be typically 109 dBA and 108 dBA, respectively. Drill body noise is suppressed by enclosure of the drill.

2.2 Previous designs

In the SIMRAC project GEN 207 a design was developed based on the acknowledged noise reduction strategies of the reactive muffler system and the dampened drill steel using an arrangement which embraced both features.

A standard SECO 215 rock drill was extensively modified both to reduce the cross sectional profile and to reduce the overall mass where possible. Items like the spade handle and the thrust leg mounting were removed and the exhaust port was reduced. With the aim of reducing the drill into the smallest possible envelope, the whole back plate was redesigned to streamline the drill to fit inside a plastic (HDPE) tube. Once mounted inside the tube, the drill takes on the function of a piston. The tube which encapsulates the drill represents the primary chamber in the reactive muffler system. The rear plate and the front plate closing off the tube are vented with a series of holes representing the impedance tubes of the system. The 'pistonised' drill is then mounted inside an aluminium tube, which now becomes the secondary chamber in the system. Referring to Figure 2.2.a It will be seen that the exhausting air from the drill will pass

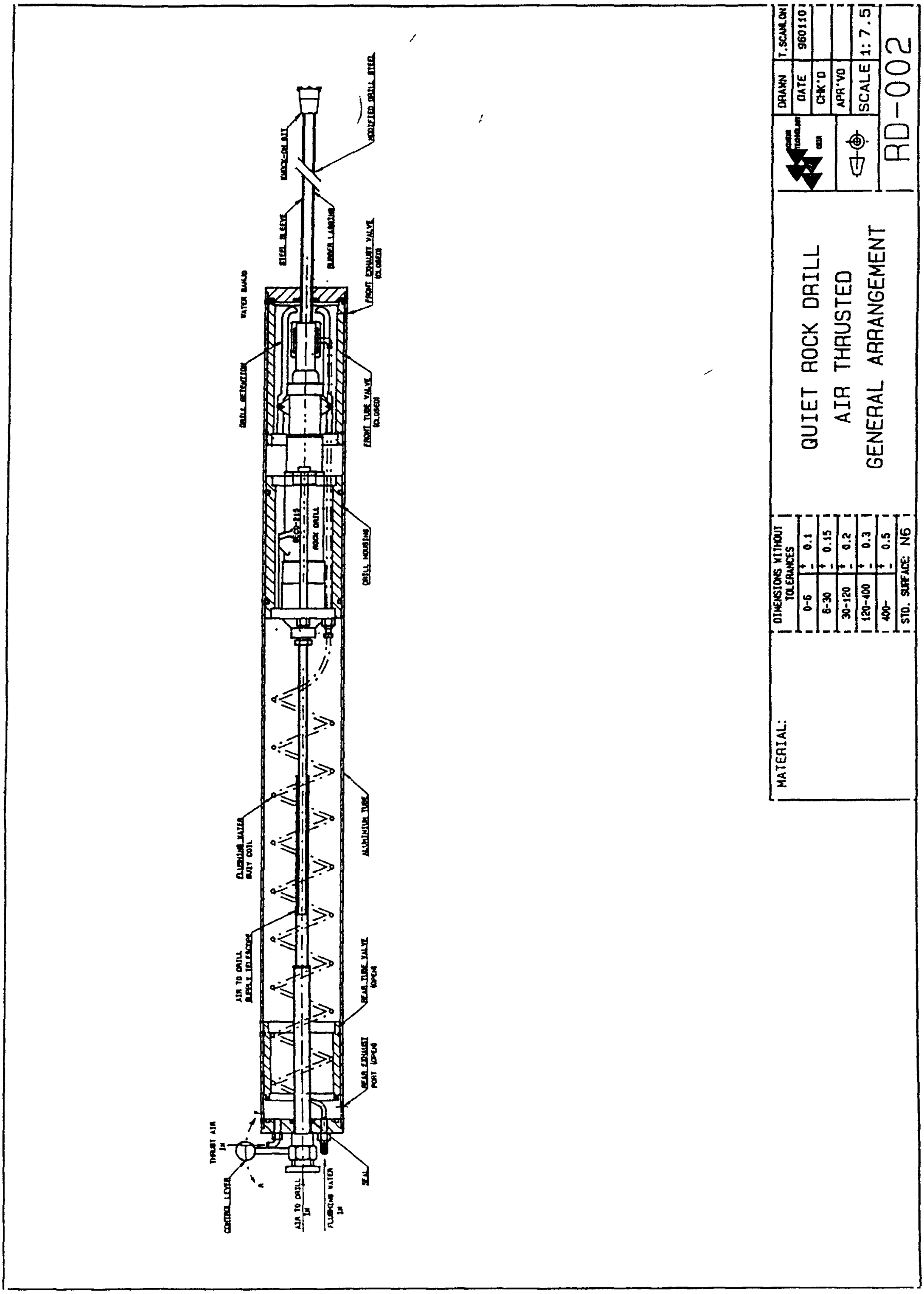

Figure 2.2.a General arrangement of previous design

from the primary chamber through the impedance holes into the main tube.

Two of the main problems encountered with this type of design is thrusting, and the other is resisting the torque generated by the drill. For this particular design the thrusting mechanism was achieved by the introduction of two tube valves, one at the front of the main tube and one at the rear. Again referring to Figure 2.2.a It will be seen that a series of exhaust holes are drilled into the main tube both at the front and at the rear. Each set of holes is served by one of the tube valves, and both valves are connected to each other by a push rod in a manner that ensures that either the front or the rear tube valve is in a position to close off the vent holes at either the front or the rear of the main drill tube.

With the rear valve closed and the front valve open, the air exhausting from the drill is free to escape to atmosphere through the open front ports. Pressurising the rear chamber by injecting a controlled air supply, the drill will be thrust forward down the tube. It will continue in this direction until either the drill pushes the front valve closed, at the same time opening the rear valve via the connecting rod, or the same action is achieved by operating the control lever at the rear of the machine. When the valving is reversed in this manner the second cycle begins. With the rear valve now open the pressurising air is now free to escape to atmosphere, and the closed front valve now traps the exhausting air from the drill driving it in the reverse direction. Regulating the thrusting air to a pressure of around 0,5 bar a thrusting force of around 1000N is available to thrust the drill.

For this design to function well sealing was vital and was often a problem. In addition to the air supply to thrust the drill a second source was required to drive the drill itself. This was supplied through a telescopic tube entering at the rear of the main tube and connecting to the rear of the drill assembly. If this was not sealed adequately then a counter force would be generated by the escaping air and could react the reversing forces.

Flushing water was another problem. Under normal circumstances this water enters the rear of the drill and travels through a core tube and enters the drill steel at the chuck bush. As sealing is unnecessary here water seepage is acceptable, and would normally fall to the ground. In the case of the sealed design the water would be unable to escape

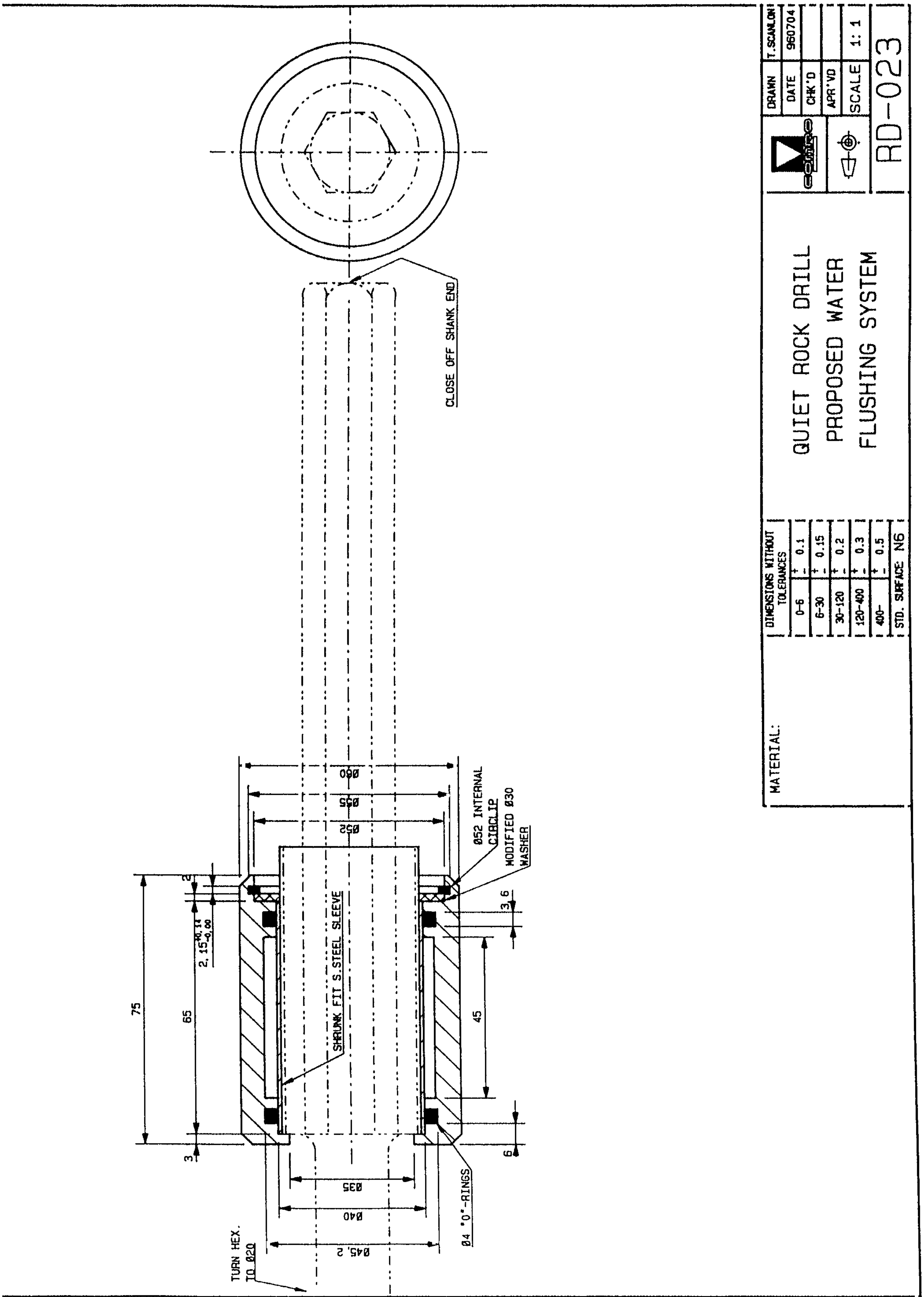

Figure 2.2.b Water flushing modifications

and would build up in the sealed tube offering further counter forces.

To overcome this problem the water flushing arrangement had to be redesigned and the drill steel modified (reference Figure 2.2.b). The drill steel collar is machined smooth and a stainless steel collar is shrunk on to it. A water banjo (rotating connection) is fitted on to this for the water connection via a plastic tube. The orifice at the rear of the drill steel is closed off and a radial hole is drilled through the wall of the collar breaking through into the cored hole of the drill steel allowing the water passage down to the bit without any leakage.

The torque problem was initially addressed by the use of two tie rods extending the length of the outer tube. As this solution added mass to the machine an alternative method was sort. It was planned to use an out of round tube for this purpose. The aluminium suppliers were approached and asked about the possibility of drawing such a tube. The initial response was encouraging and we proceeded accordingly. However, as they proceeded with their development the problem was to prove some what more formidable. Apparently, the problem lay with maintaining the tolerances and profile over a 2 m length.

Another source of noise that was addressed was that of the drill steel it self. The unmodified drill steel acts very much like a tuning fork. This noise was reduced by the application of a technique referred to previously and known as surface reactive damping. This was achieved by machining the off the hexagon section forward of the collar to a diameter of 20mm. This is then covered by a 1mm thick covering of natural rubber over which a thin walled steel tube is fitted. The effects of this type of modification have proven to be effective.

3 Research methodology and process

3.1 Design

While each of the significant noise sources within a conventional rock drilling system has been addressed in previous work by many researchers, few of the solutions have been successfully implemented. However, previous work in this project has shown that the problems that restricted implementation of these solutions can be resolved if the thrust is directed along the axis of the drill, i.e. 'in-line' thrusting. According to experiment and underground measurements 'in-line' thrust can provide for performance increases of up to 100 percent, as well as facilitate the drilling of straight holes, thereby minimising contact between the drill steel and the hole.

3.1.1 Thrust requirements

A mathematical analysis (Hustralid 1971:247) indicates that for a pneumatic machine the minimum thrust force required to ensure that the bit and rock are in contact when the impact wave arrives can be determined from the following relationship.

$$F_t = \frac{\bar{f}}{30}(1+\beta)\int_0^{\tau} \sigma_i dt \qquad (3.1)$$

where	σ_i	=	incident stress (longitudinal wave) as a function of time (KPa)
	τ	=	duration of incident wave (sec)
	β	=	coefficient of momentum transfer from drill steel to piston, normally $0 \leq \beta \leq 0.2$
	F_t	=	minimum required thrust (N)
	f	=	actual blow frequency (Hz)

It is important to note that the thrust required for optimum drilling depends on the particular drill and is essentially independent of rock type and bit diameter. Furthermore, the method used by Hustralid is limited to the determination of the thrust required to restore bit/rock contact and does not include any allowance for the fact that in rock drills such as the SECO 215 the percussion and rotation are mechanically linked causing the drill to stall if excessive thrust is applied. In recognition of this it was decided that the thrust requirements be determined by experimental drilling in Norite. The relationship between thrust and drill penetration rate for a percussive rock drill is shown in Figure 3 1 1.a.

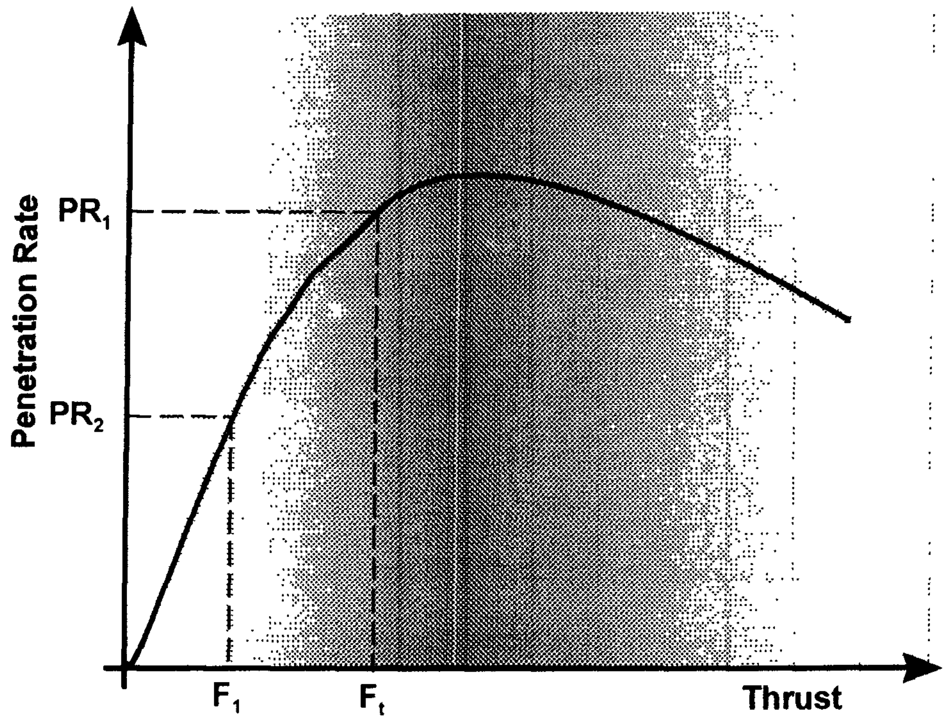

Figure 3.1.1.a A typical thrust-penetration rate curve for a percussive rock drill

When a piston impacts the end of a drill steel an incident wave having a certain amplitude travels towards the bit-rock interface. The shape and amplitude of the wave that is reflected back down the drill steel (away from the interface) depends on the conditions pertaining at the interface. If the bit and rock are not in intimate contact, as may occur under conditions of under thrust, a free end reflection will result. Successive incident and reflected waves will continue to be of approximately the same amplitude as the initial incident wave and decreasing only as a result of hysteresis losses and dispersion until bit-rock contact is re-established. On re-establishment of the bit-rock contact a rapid decrease in amplitude will occur as a result of energy transfer to the rock. If the bit and rock are in contact when the first incident wave arrives the amplitude of the reflected wave will be much smaller than that of the incident wave again as a result of energy transfer to the rock. As fatigue life decreases exponentially with increasing peak-to peak stress amplitude it is important to keep the number of high-level stress reversals as low as possible. This minimum occurs when the bit and rock are in contact each time a new stress wave arrives at their interface. The thrust force F_t required to achieve this condition is determined from the relationship of equation 3.2. A typical curve for penetration rate as a function of thrust at a given air supply pressure is shown in Figure 3.1.1.a.

If the applied thrust is F_1 rather than F_t the penetration rate is approximately half that at optimum thrust. However, the machine continues to provide the same energy to the drill steel irrespective of thrust. The energy not absorbed by rock penetration must therefore be dissipated as hysteresis heating within the drill steel which requires a large number of cycles of stress reversal. Assuming that these cycles are high level stress reversals then the fatigue life of the drill steel will be severely reduced. Typically, the reduction in fatigue life may be by a factor of 3 when operating at half the optimum thrust. This reduction is in addition to the fatigue limitations of the drill steel incurred as a result of bending loads resulting from the non-axial thrust produced by a conventional thrust leg arrangement. As a result of these factors and following several drilling test using a drilling test rig an optimum thrust force for a SECO 215 machine was determined to be 1000 N.

3.1.2 Thrust mechanism

In order to provide 'in-line' thrust a concept was developed by which a rock drill with minor modifications became a piston within what is effectively an enlarged thrust-leg tube. This initial development of this concept is covered in the SIMRAC report on project GEN 207. The general layout of this concept is shown in Figure 2.1.a. During surface testing of this prototype several drawbacks were identified which necessitated the development of an alternative method of applying thrust. More specifically the difficulties were as follows:

- even though relatively low air pressure were required for the thrust the numerous seals required precluded a mine worthy design.
- a sealed system required that the flushing water system should also be sealed.
- the relatively low stiffness of a larger diameter cylinder with a low internal pressure provided insufficient dynamic damping of the drill.
- the dynamics of the system, the larger diameter of the tube (in comparison to a standard thrust leg) and the consequentially lower air pressure for thrust necessitated an extremely precise pressure control device

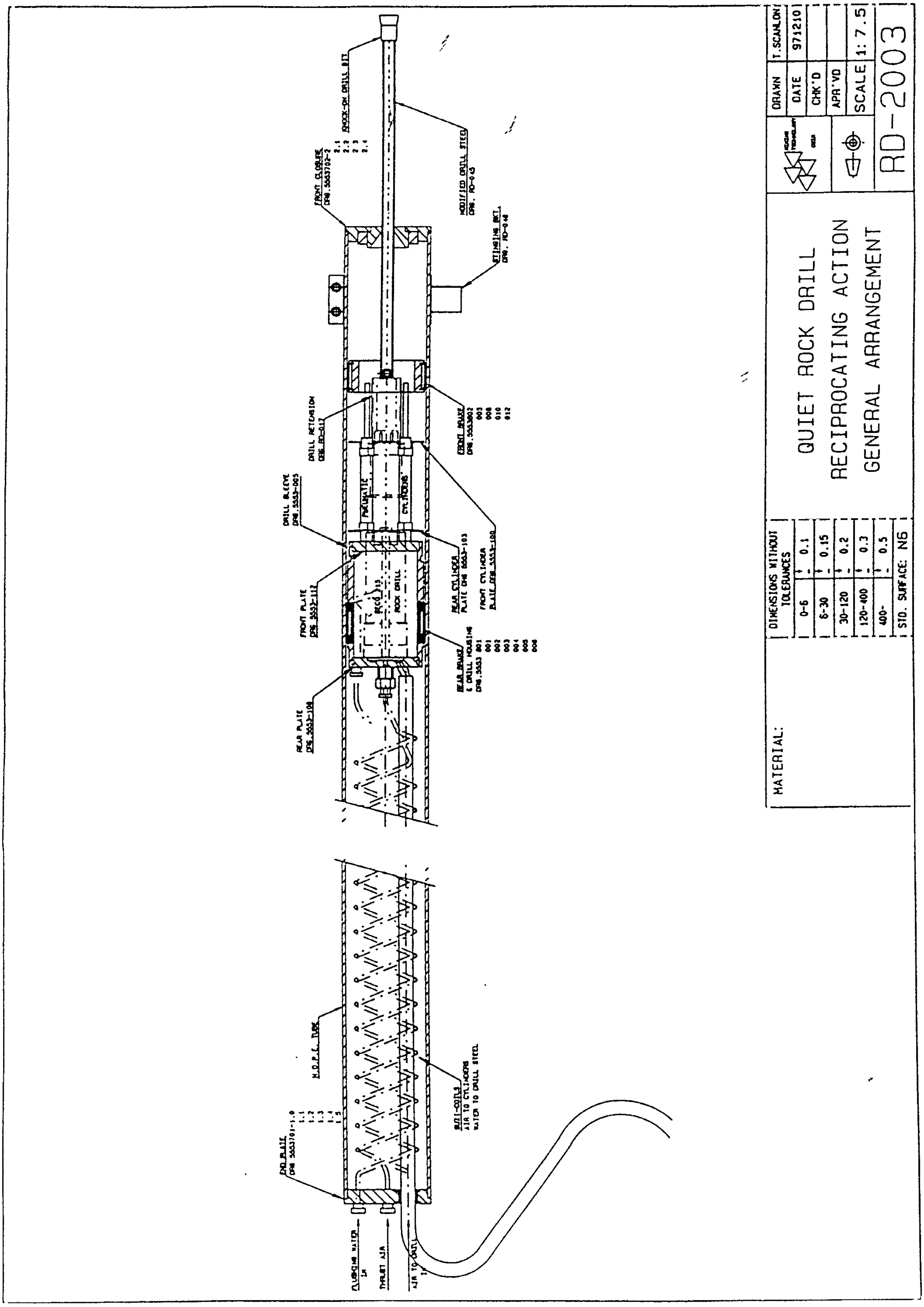

Figure 3.1.2.a General arrangement of reciprocating action drill

To resolve these difficulties an alternate method of providing the thrust was required which maintains the 'in-line' features. A potential method was developed based on a standard 'beam crawler' concept. The general arrangement of such a system is shown in Figure 3.1.2.a. Referring to Figure 3.1.2.a it can be seen that a standard rock drill (Seco215) has been used in this design. The cross sectional profile of the drill has been reduced to a minimum by redesigning the rear back head and the removal of components that have become redundant in this application, such as the 'D' handle and the existing air inlet pipe etc. It will be seen that the drill is encapsulated in a plastic tube (HDPE) thus creating the first volume in the pi reactive silencer system. This tube is closed off at each end with steel discs. In both discs are a series of holes which represent the impendence tubes to the secondary volume. The whole assembly traverses along the length of another plastic tube (cylinder) which provides the second volume in the pi reactive silencer system, and this combination of piston and cylinder provides the in line thrust configuration.

The in line thrust mechanism is induced by the use of four pneumatic cylinders and two sets of brakes. Again referring to Figure 3.1.2.a it will be seen that the plastic tube holding the drill supports a drum brake, comprising three symmetrical shoes energised by inflatable inner tubes. The four pneumatic cylinders are attached to the front of the drill assembly and a similar braking arrangement is fitted to the end of the piston rods. With the above arrangement the following thrust cycle is generated.

While the rear brake is engaged and the front brake is off the four pneumatic cylinders extend to their limit of 100mm. (No drilling) At this point the front brake is engaged and rear brake releases and the cylinders start to retract, effectively pulling the drill along the tube (drilling) until the cylinders are fully retracted and the cycle is ready to restart, resulting in a crawling action.

The crawling action can be reversed at any time during the forward or reversing action by the use of the control lever at the rear of the unit. When the drill is allowed to move to its extremities in either direction, limit switches are activated and the direction automatically reversed.

Air to the drill is supplied by a conventional air hose being fed in through the rear closure plate with an air pressure regulator conveniently located close to the drill. This allows the operator to control the thrust and prevent stalling of the drill. Air to the pneumatic system and flushing water to the drill are supplied through two 'suzy coils' connected from the rear closure plate and the rear plate of the drill assembly.

In the conventional arrangement of a pneumatic rock drill and thrust leg the thrust is applied at an angle to the direction of drilling which varies from typically 30 to 60 degrees. Standard thrust legs have an internal diameter of 69 mm which at a 60 degree angle will provide a thrust of approximately 1000 N . The same force can be provided by four 25 mm internal diameter cylinders operating in tandem. Four such cylinders of 100 mm stroke can be mounted in a frame surrounding the rotation section of a SECO 215 rock drill in such a manner that they do not increase the overall enclosure envelope and therefore can be fitted within the same tube enclosure as used previously.

Calculations and analysis indicated that a conventional drum brake would not be able to supply the braking force to react the required thrust at the air supply pressures generally available underground (400 to 500 kPa). At the available air supply pressures sufficient braking force could be generated if the pressure could be applied radially over the full braking surface. Such configuration prevails in inflatable seal systems and this method was used to develop the front brake which was a 4 shoe disc arrangement energised by inflated tubes. At 150 mm diameter, a face width of 15 mm and a supply pressure of 500 kPa the brake should provide frictional resistance of 1060 N at a friction coefficient of 0.3. This was considered sufficient for the initial laboratory trials.

For the reset part of the thrusting cycle when the cylinders are extending to reposition the front brake it was assumed that the required braking would be relatively small and therefore a pair of small (ϕ16 piston) pneumatic cylinders were used acting radially against the main outer tube.

This arrangement worked and a thrust rate of 800 N was available. However, when the drill was started up and the subsequent vibration and dynamics were bought to bear on the system the whole braking arrangement failed and adequate thrust was lost due to the drill assembly creeping against brake force. This was especially true with the rear brakes which were totally inadequate to resist the dynamic forces produced by the drill even when operating in over travel. Extending the contact area of the rear brakes via a band arrangement to distribute the brake forces more evenly only marginally improved the system. This creeping problem was further aggravated by the presence of oil from the exhausting air. This oil present in the exhaust air effectively lined the wall of the tube with a film of oil and lubricated the braking surfaces.

Clearly a more aggressive braking system was required, with a larger braking surface and one that would actually grip the inside of the tube. This was achieved by increasing the effective face width of both front and rear brakes and energising them with larger inflatable tubes. The tubes finally used for energising the brakes were in fact off the shelf wheelchair inner tubes.

The initial arrangement consisted of simply four pneumatic cylinders, two air brakes and a mechanically operated 3-5 way spool valve which was operated by an actuator arm connected to the front brake. In laboratory testing this system proved to be both simple and effective if somewhat erratic in that a full movement of the drill was not always achieved. Further investigation revealed that this was a result of the brakes not releasing immediately when the spool valve was switched. To resolve this problem rapid venting valves were introduced immediately upstream of each brake.

There were early problems with the spool valve being mounted parallel to the drill axis. The hammering action of the drill had the effect of shunting the spool and causing erratic cycling, short strokes and occasional stalls.

An initial attempt to resolve this problem was to rotate the valve through 90 degrees. While this provided a significant improvement it did not fully resolve the occasional stalling problem and consequently the design was changed to use a combination of 3-2 way valves mechanically linked to the movement of the cylinder rods. This effectively resolved the problems experienced with the harmonics and the timing of the system.

With the addition of automatic and manual thrust reversal the pneumatic circuitry at this stage had become quite complex (Figure 3.1.2.c) and prone to stoppages due to twisted hoses and loose connections. A schematic of the pneumatic circuit is included in Appendix B

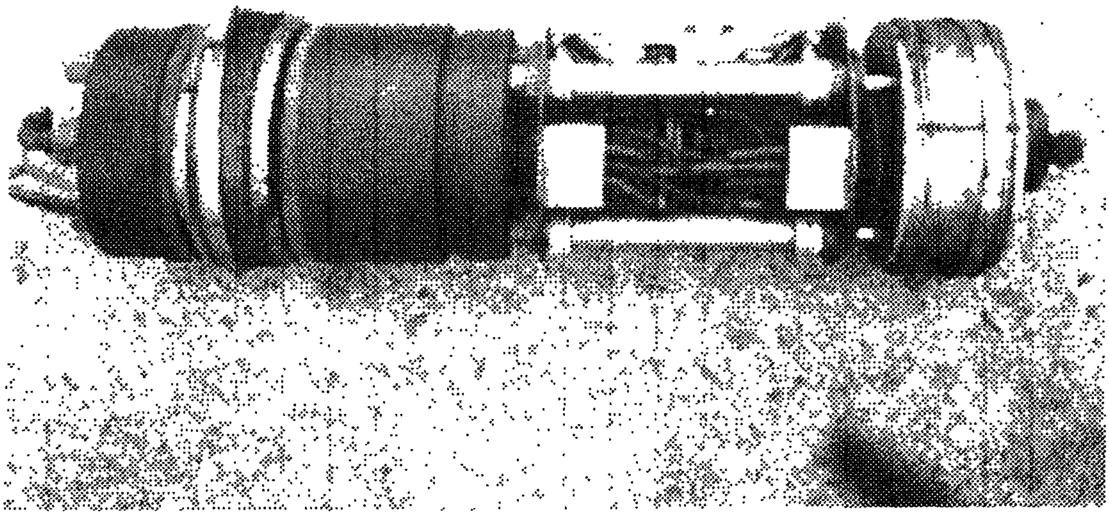

Figure 3.1.2.b General view of the pneumatic system

3.1.3 Drill Retention

The normal drill retention arrangement was changed to suit the restraints of the plastic tube. The mounting boss and the retention bracket were removed as they could no longer function while operating inside the tube. This resulted in a reduction in mass but the trade off was a cumbersome and time consuming replacement. The detail of this modification is shown in drawing RD-017 of Appendix A. Although this works in the interim, further work in this area will be needed to simplify drill steel replacements.

3.1.4 Collaring

At the beginning of the drilling operation as the drill bit attempts to make a start the noise emitted during this phase diminishes as the drilling progresses, to a point where it remains fairly constant. To reduce this initial high noise level, a bellows type shroud was fitted to the front of the drill unit. This effectively muffled the noise during this collaring phase and indicated that a similar fitting should become part of the forward assembly. (Figure 3.1.5.c)

3.1.5 Stinging

To enhance operator acceptance of a quiet machine an objective of the current work was that the overall operator effort required for drilling should be reduced. This aspect is addressed via the elimination of the requirement for re-stinging by providing for the drilling of a hole in one continuous operation. However, this is but one element of the operator input during drilling and therefore does not address issues such as the required downward force to balance the upward component of the conventional thrust leg, the effort required to prevent the drill from falling over and the ongoing adjustment of the thrust pressure. To minimise these operator inputs a stable self supporting drilling system is required. To achieve such a system requires a minimum of three reaction point which will include one at the face and either two on the footwall or one on the footwall and one at the hanging. The thrust force of the machine may be reacted either at the face or at the reaction points at both footwall and hanging. Furthermore, the selected arrangement must be able to provide the necessary reaction to the rotation torque which ,in the case of a typical pneumatic rock drill, is approximately 10 Nm . It was elected to react the thrust force at the face using the device shown in Figure 3.1.5.a

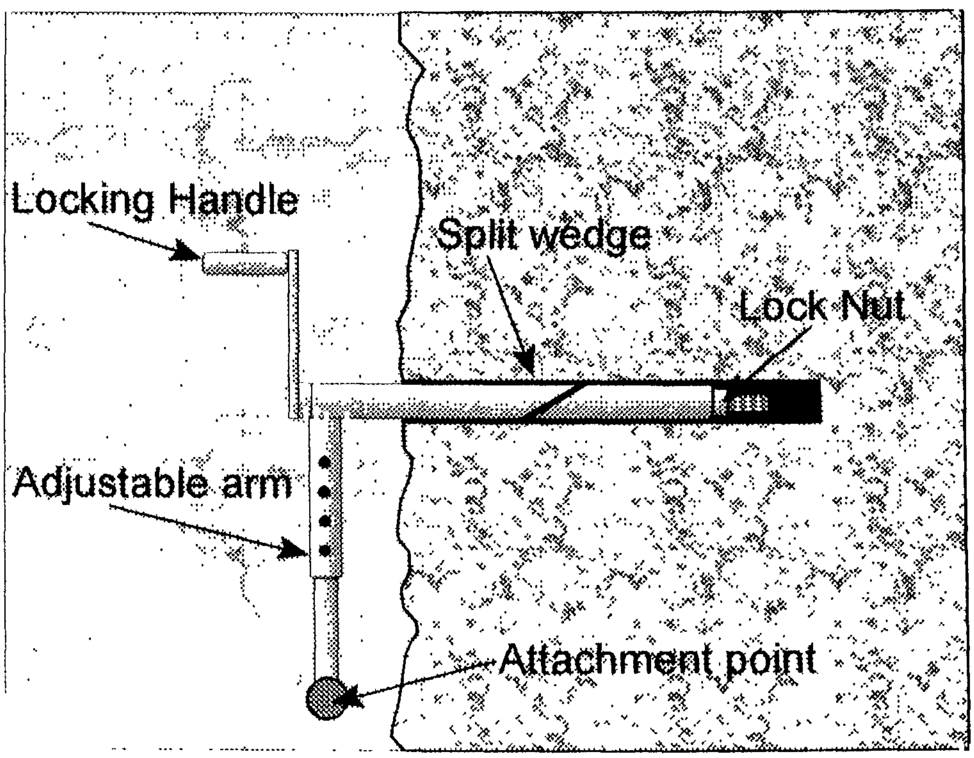

Figure 3.1.5.a Front attachment device

In the illustration (Figure 3.1.5.a) it will be seen that the anchor features an eccentric locking device, that is inserted into a previously drilled hole and the operator can set the attitude of the drill for the next hole. The rear of the machine is supported by an adjustable prop. When the unit has been rigged the operator can start the drill and retire behind the drill to the comparative safety of the first line of props. He can either remain here until the hole has been drilled or he could commence the rigging of a second machine. Thereafter a piggy back operation could be implemented. The general arrangement of the drilling system during surface testing is shown in Figures 3.1.5.b and 3.1.5.c.

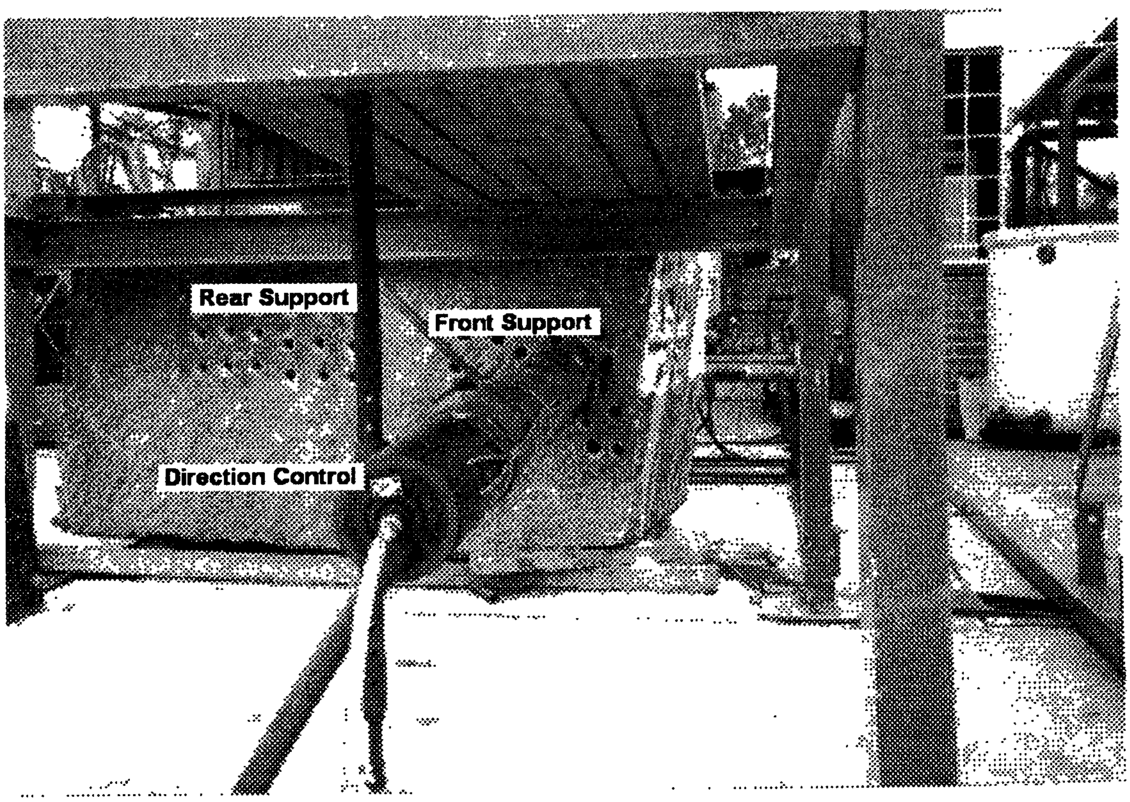

Figure 3.1.5.b General view of drill system during surface testing

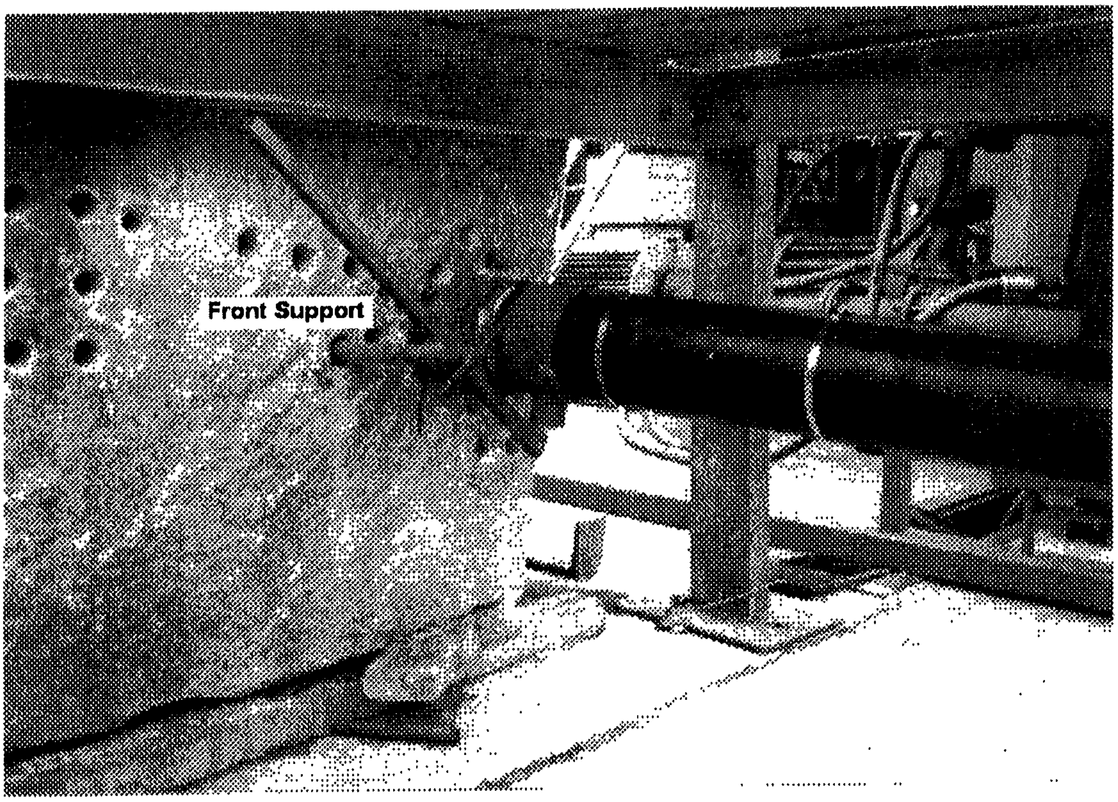

Figure 3.1.5.c General view of front attachment used in surface tests

3.2 Surface testing

Four prototype machines were constructed to the design presented in the appendices and generally as shown in Figures 3.1.2c and 3.1.5.b. The machines were tested on surface in a simulation of a stope as shown in Figures 3.1.5.b and 3.1.5.c. A total of 179 holes were drilled into Norite blocks distributed over the four machines (80,40, 33 and 26 metres)

The penetration rate as a function of available thrust from the crawler system is shown in Figure 3.2.a. In this determination the thrust was varied by using an independent air supply to the thrust mechanism and adjusting the supply pressure. For comparison it should be noted that the equivalent performance for a similar drill operating at the same pressure but with a conventional thrust leg and an experienced operator is 150 mm per minute drilling into Norite. The quiet drill therefore more than matches the drilling performance of a standard machine configuration

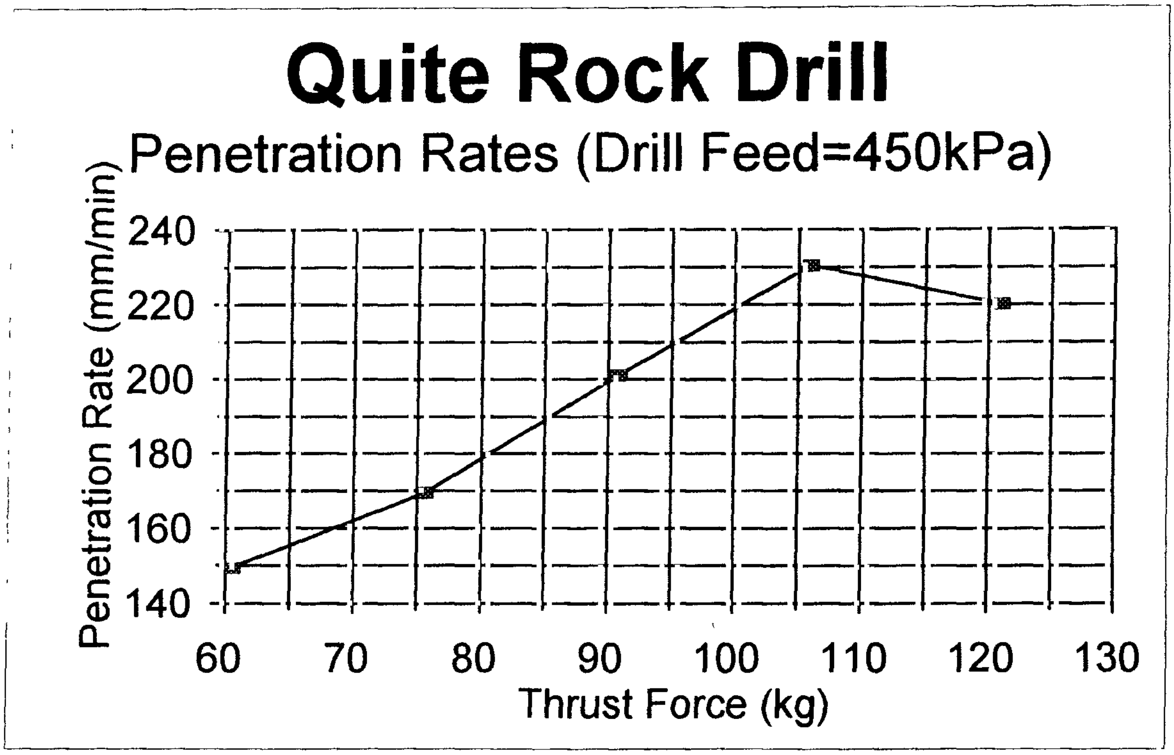

Figure 3.2.a Penetration rate test results

During the drilling tests noise level measurements were recorded for each hole drilled establishing average noise levels of 92-93 dBA during collaring and 90-92 dBA during drilling. The efficacy of the front bellows attachment in reducing the noise levels during collaring was found to be marginal providing less than 0,5 dB reduction.

During the drilling tests several problems were encountered as follows:

- Two drill steels failed by fatigue fracture at the collar to shank interface.
- On four occasions the steel shroud on the drill steel moved forward as a result of the vibration and pushed the drill bit off. This particular issue was resolved by additional crimping of the outer tube using a standard pipe cutter.
- Above 40 metres of drilling there were several (7) failures of the pneumatic circuit of the crawler mechanism. The failures were all the result of leaks resulting from either loosening or fatigue failure of fittings or punctures in the brake energiser tubes.

- There were one or two occasions when the thrust system failed to operate as a resulting of ice in the pneumatic control lines but this only occurred when the ambient temperature was low (approximately 10 degrees) and is not anticipated to become an issue in an underground environment.

During testing there was a strong positive feedback from the operators regarding the ability to 'stand back' from the machine once drilling had commenced.

It was noted that there was little evidence of air borne drill lubricant issuing from the device with the majority of the lubricant either being retained within the outer tube or flushed out with flushing water leakage through the drain holes.

4 Discussion of results

The current model has the distinct advantage of having fewer modifications to both to the drill and the drill steel and having the aluminium tube replaced with a cheaper plastic one. It required less demanding sealing and the flushing water arrangement remained as supplied.

The braking system on this unit was subject to much deliberation, rethought and development . Some of the earlier brakes feature two small pneumatic cylinders with a stroke of 10mm acting directly into the plastic tube for the rear brakes. The concentration of force was such that the tube could be seen to deform at the point of application and the accompanied braking effect was not good either and generally inadequate to react the dynamic forces of the drill. Subsequent designs using the same cylinders but using a braking band attached to it and pivoting the other end. This had the effect of distributing the braking force around the tube, but the braking force was still not adequate.

The final design is a drum brake type with a much wider shoe and energised by inflated rubber tubing. The brake shoes were manufactured with sharp annular grooves and actually attacked the inside of the plastic tube on application The presence of plastic particles in the grooves suggested that the brakes were actually honing the inside of the tube. How much of a problem this would turn out to be remains to be seen, bearing in mind that the cheaper plastic tube could become a sacrificial component and could be replaced periodically. It was determined that the applied braking force is more than double the force necessary to provide the required thrust and is required to resist the dynamic loads of the machine. This situation indicates that some further attention should be given to the method of attaching the thrust device to the drill preferably with a system that provides some dynamic damping.

A more positive braking system such as a caliper brake acting on a screwed rod extending the length of the outer tube with dynamic damping between the thrust device and the drill would be a significant improvement.

A feature that showed itself especially on cold winter mornings was a tendency to ice up. This is a common phenomena when air is compressed and allowed to expand but did not occur later in the day and therefore is not expected to become an issue in typical underground environments

The pneumatic control circuit is complex but does provide for full automation of drilling with automatic retraction on completion of the hole. Some of the complexity derives from the use multiple components which during commercialisation could be incorporated into single units.

A particular advantage of the crawler mechanism is that it can be applied to a standard SECO rock drill with no modification other than the removal of the spring retainer.

5 Conclusions and recommendations

From results of the surface testing of the quiet blast hole drilling system there is very positive indication that this type of arrangement could be re-engineered during commercialisation into an effective mining tool. Major progress has been achieved in the production of a device that can drill at rates better than conventionally thrust drills at significantly lower noise levels. Comparing the noise levels of a standard unmodified drill of 115dB against that of the prototypes at 92dB there is real cause for optimism regarding a major contribution to the reduction of noise induced hearing loss in the South

African mining Industry.

Previous attempts at noise reduction of pneumatic machines have met with significant operator resistance because of the reduced performance of these machines. The fact that the drills are self thrusting and can drill unmanned after being rigged will significantly reduce operator input which, with the maintained performance levels, should provide for a high level of operator acceptance.

The complexity of the pneumatics remains a concern in terms of cost and reliability, and should be re-engineered during commercialisation. Similarly the inclusion of dynamic damping within the attachment of the thrust device to the drill will afford major improvements in reliability and permit the use of a lower braking force.

The reactive damping of drill steels is an effective method of noise reduction and while not applicable to conventional drilling should however, be given serious consideration for application with drilling rigs or any other system that provides for 'in-line' thrust.

In conclusion is firmly recommended that the designs presented here form the basis of the commercialisation of an effective 'quiet' blast hole drilling system.

6 References

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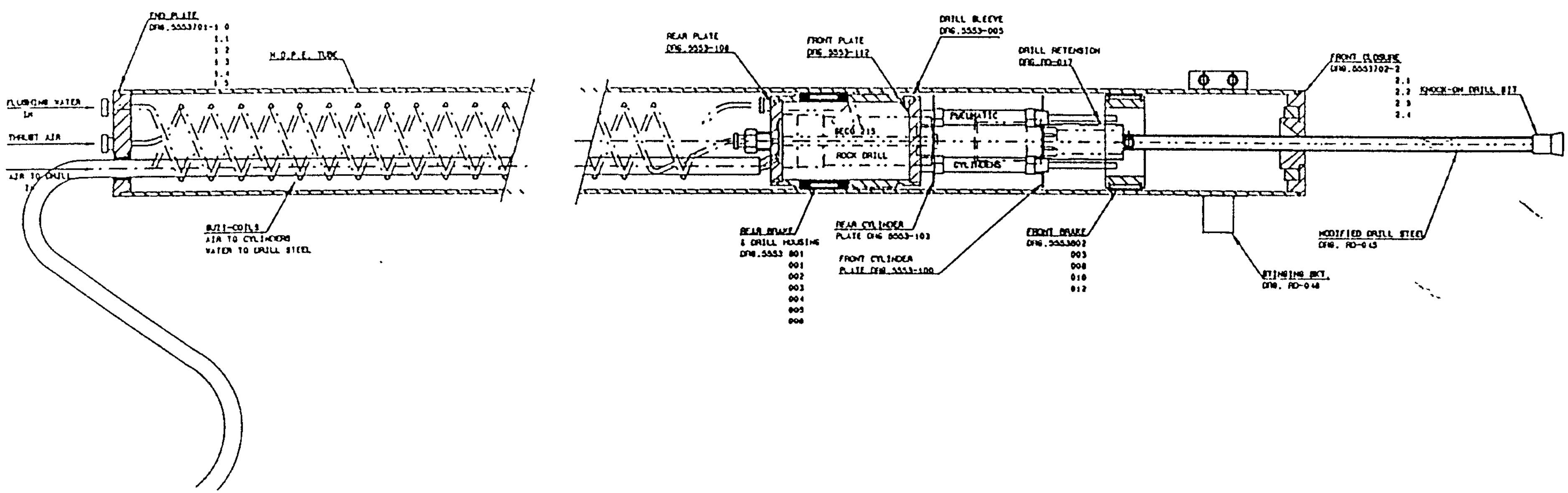
7 APPENDICES

The following appendices include the development and manufacturing drawings of the quiet blast hole drilling system, the thrust mechanism, the drill steel modifications and the stinging arrangement.

7.1 Appendix A Blast hole drilling system drawings

This appendix includes the general arrangement drawing and part detail drawings of the quiet blast hole drilling system.



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30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD. SURFACE: N6	

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RECIPROCATING ACTION
GENERAL ARRANGEMENT

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APR'VD	
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RD-2003

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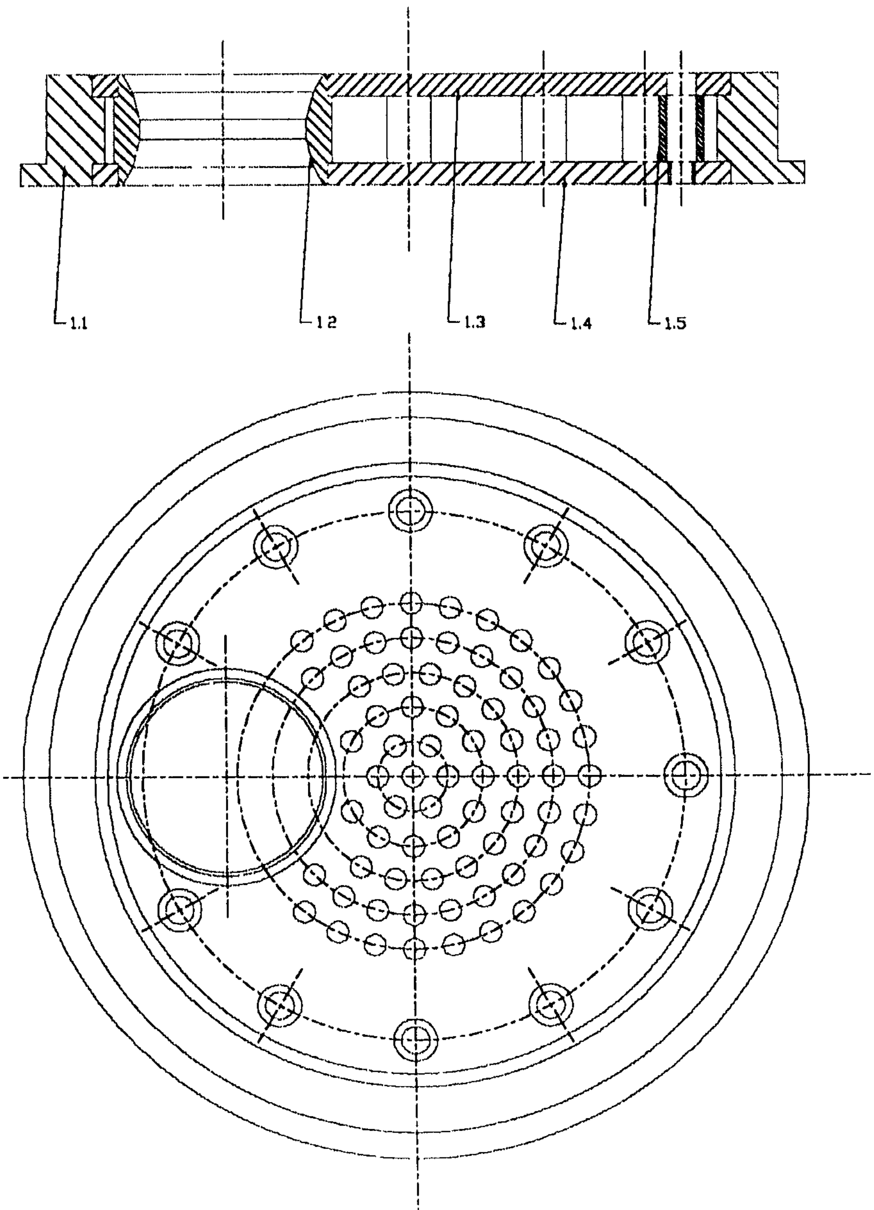

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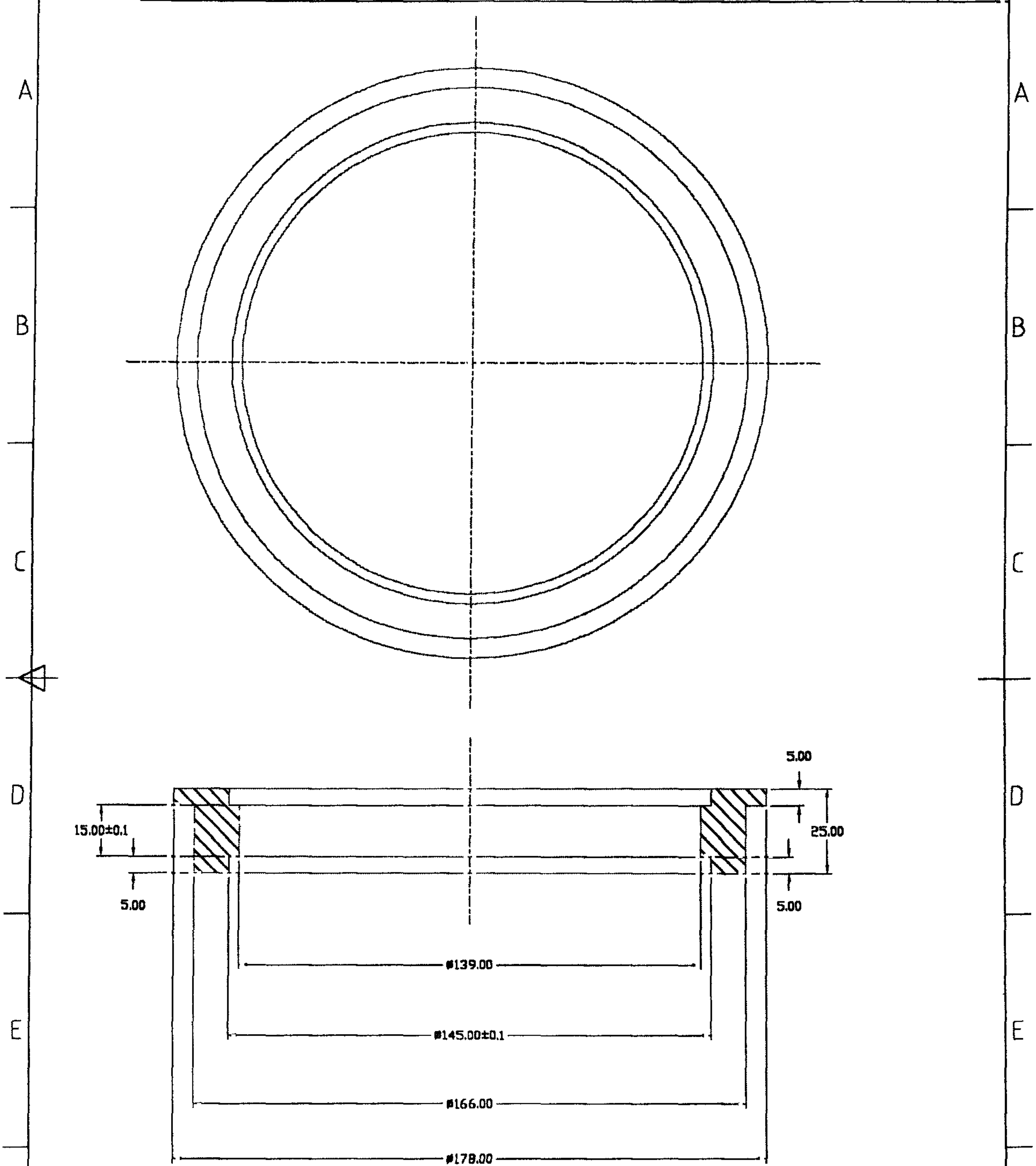

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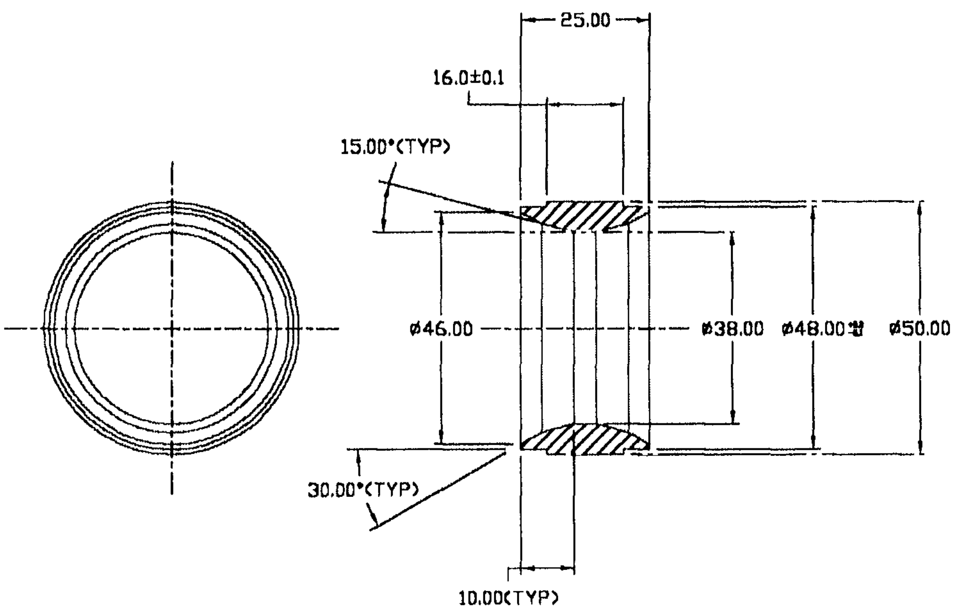

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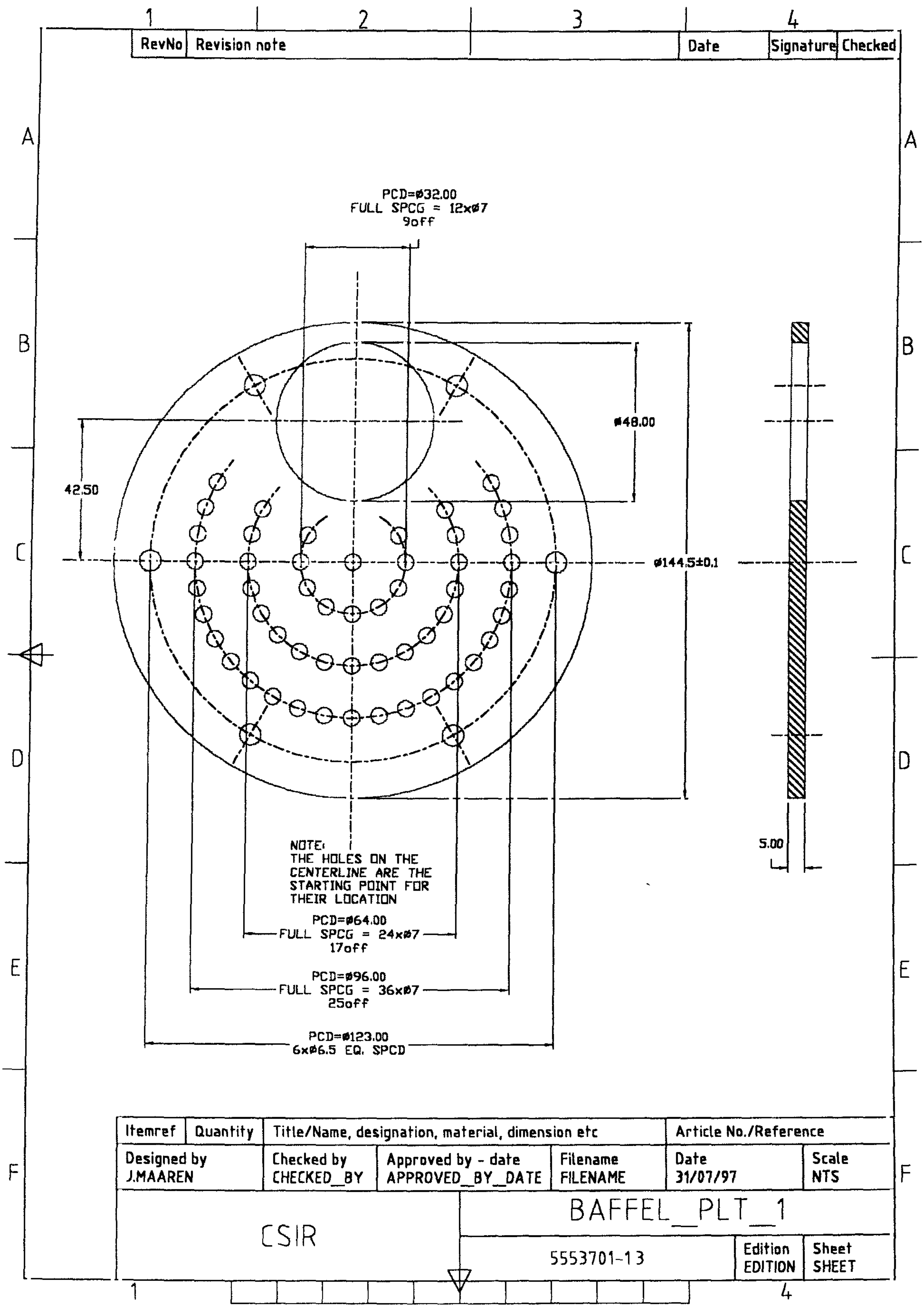
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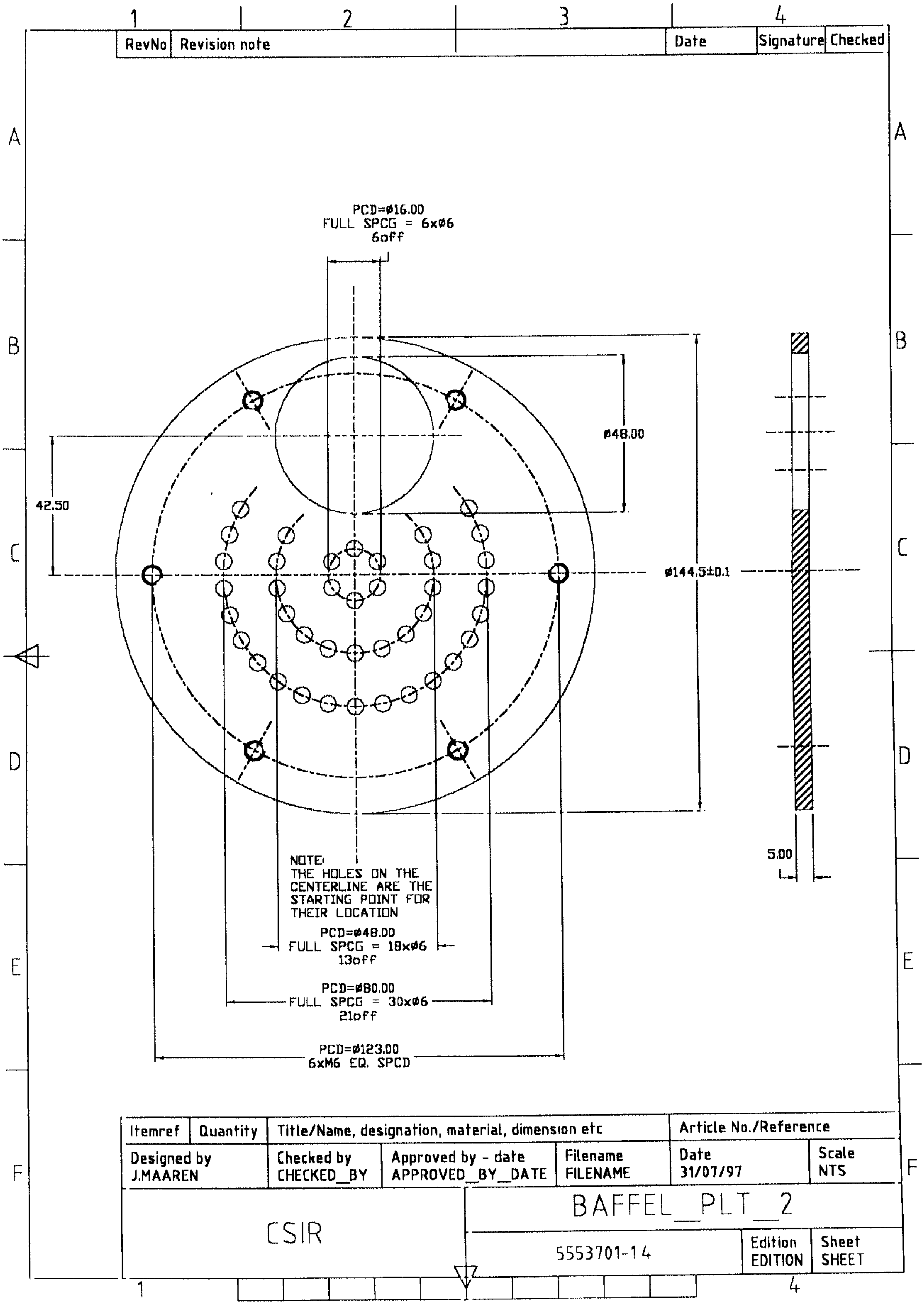

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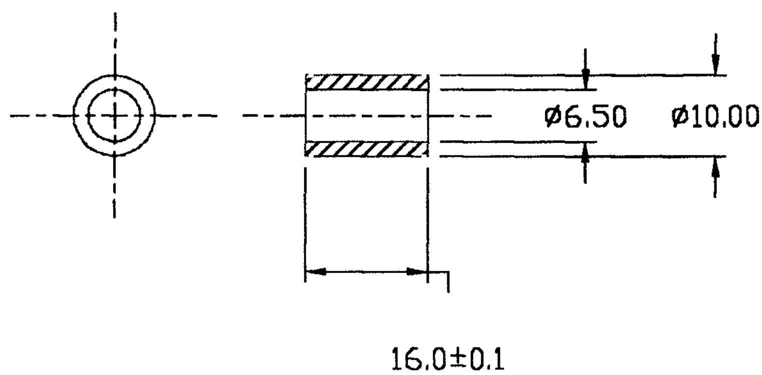

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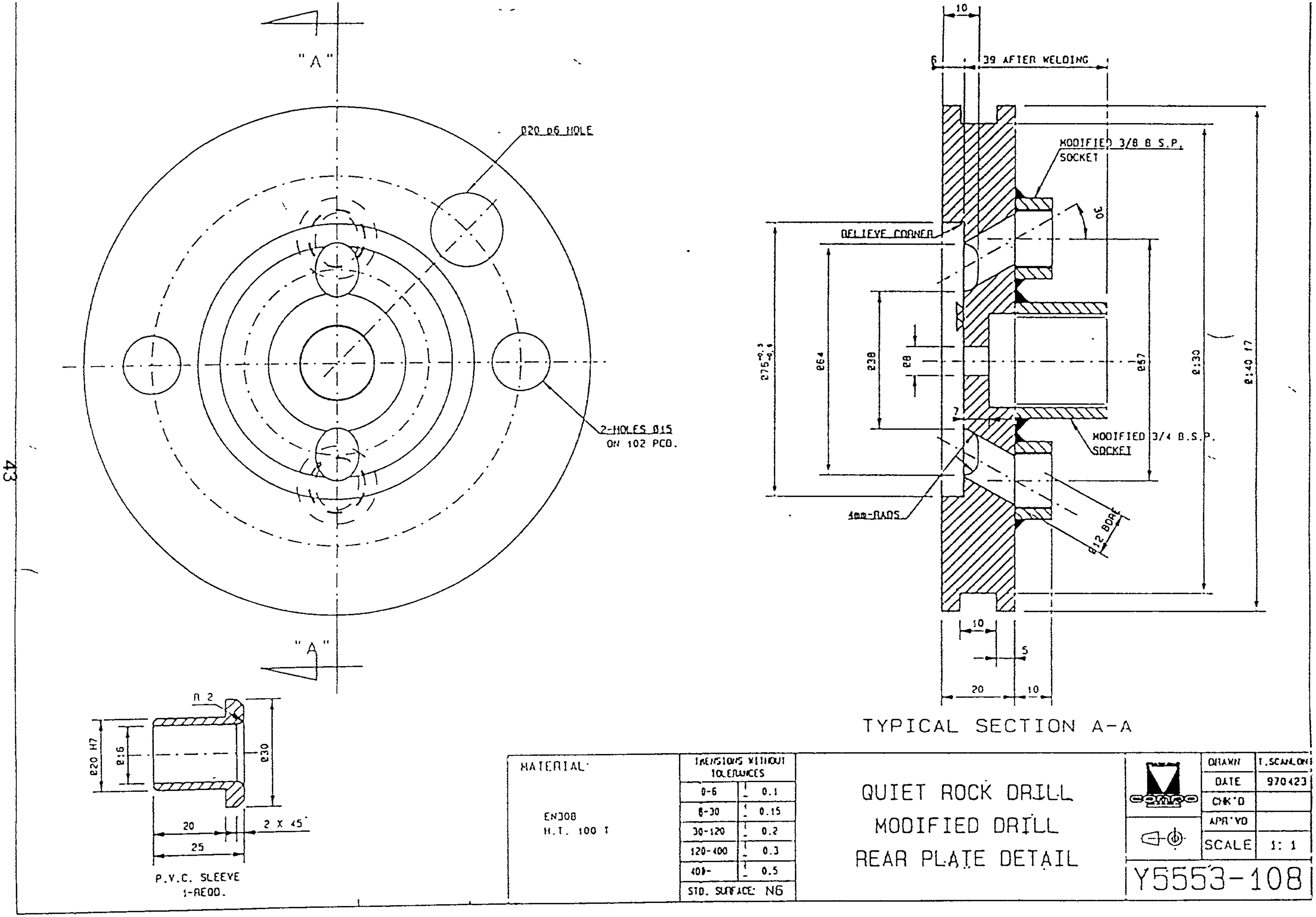
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30
RELIEVE CORNER
Ø75
Ø64
Ø38
Ø8
7
Ø57
Ø130
Ø140 f7
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SOCKET
4mm-RADS
Ø12 BORE
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5
20
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R 2
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2 X 45°
25
P.V.C. SLEEVE
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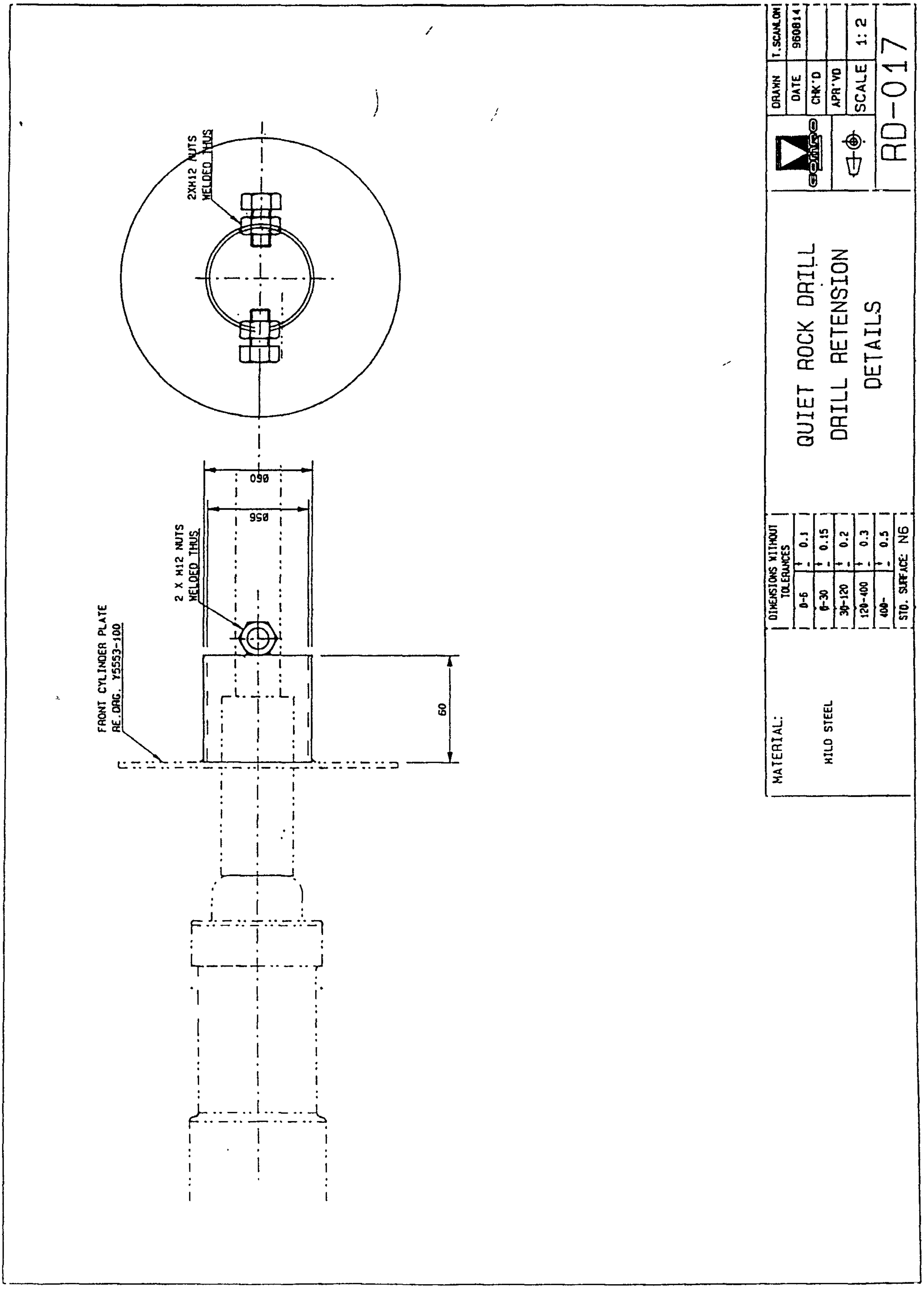

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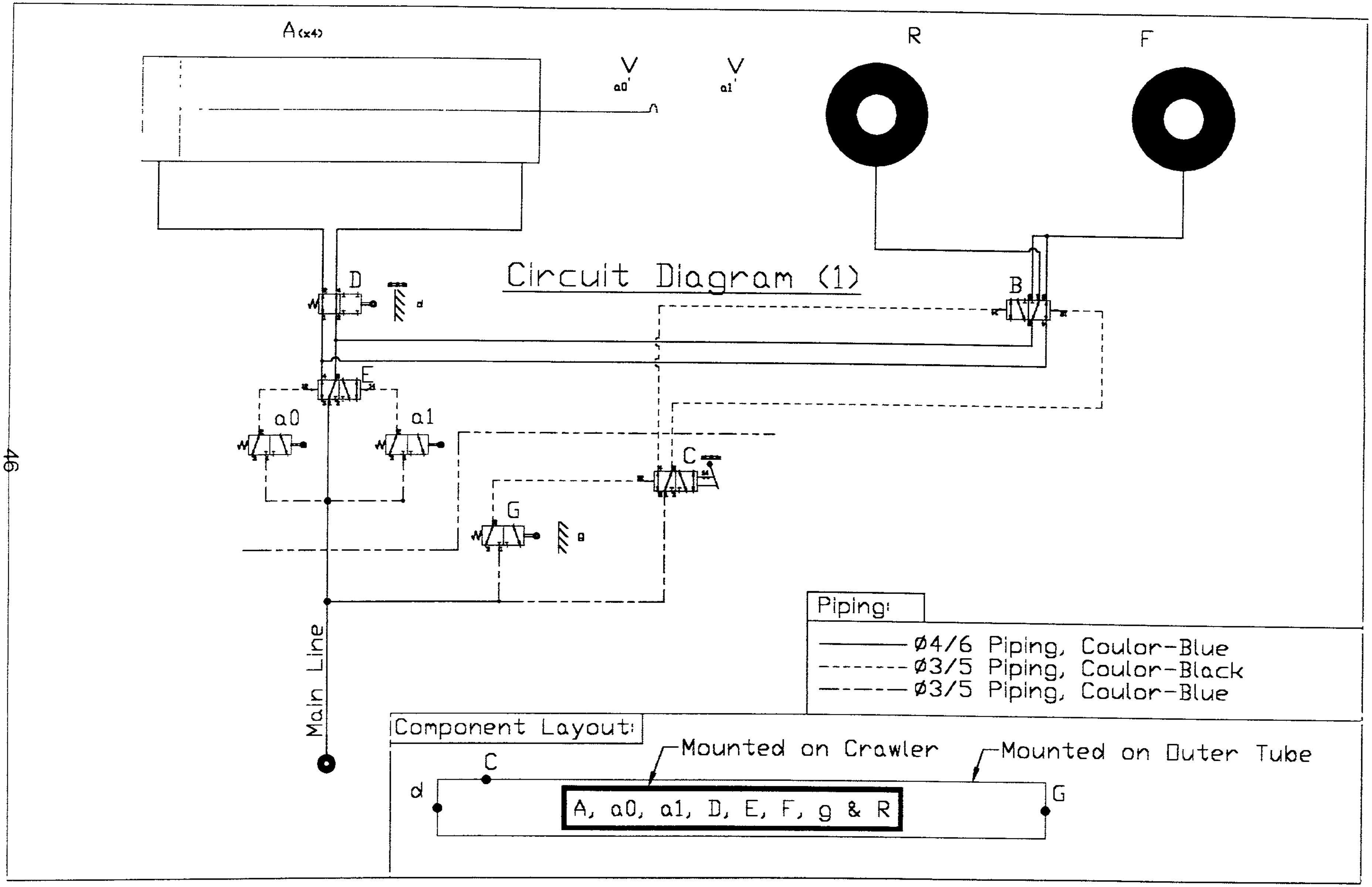
7.2 Appendix B Thrust mechanism drawings

This appendix includes the general arrangement drawing and the part detail drawings of the thrust mechanism.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V a0'
V a1'
R
F
B
D
d
E
a0
a1
C
G
g
Main Line
Piping:
Ø4/6 Piping, Coulor-Blue
Ø3/5 Piping, Coulor-Black
Ø3/5 Piping, Coulor-Blue
Component Layout:
Mounted on Crawler
Mounted on Outer Tube
C
d
G
A, a0, a1, D, E, F, g & R

RevNo	Revision note	Date	Signature	Checked

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6	PRESSURE BUSH	1	5553006A.DWG
5	INNER DRILL SLEEVE	1	5553005A.DWG
4	O-RINGS	8xø5.3	5553004A.DWG
3	REAR BRAKE SHOES	1 (x3)	5553003A.DWG
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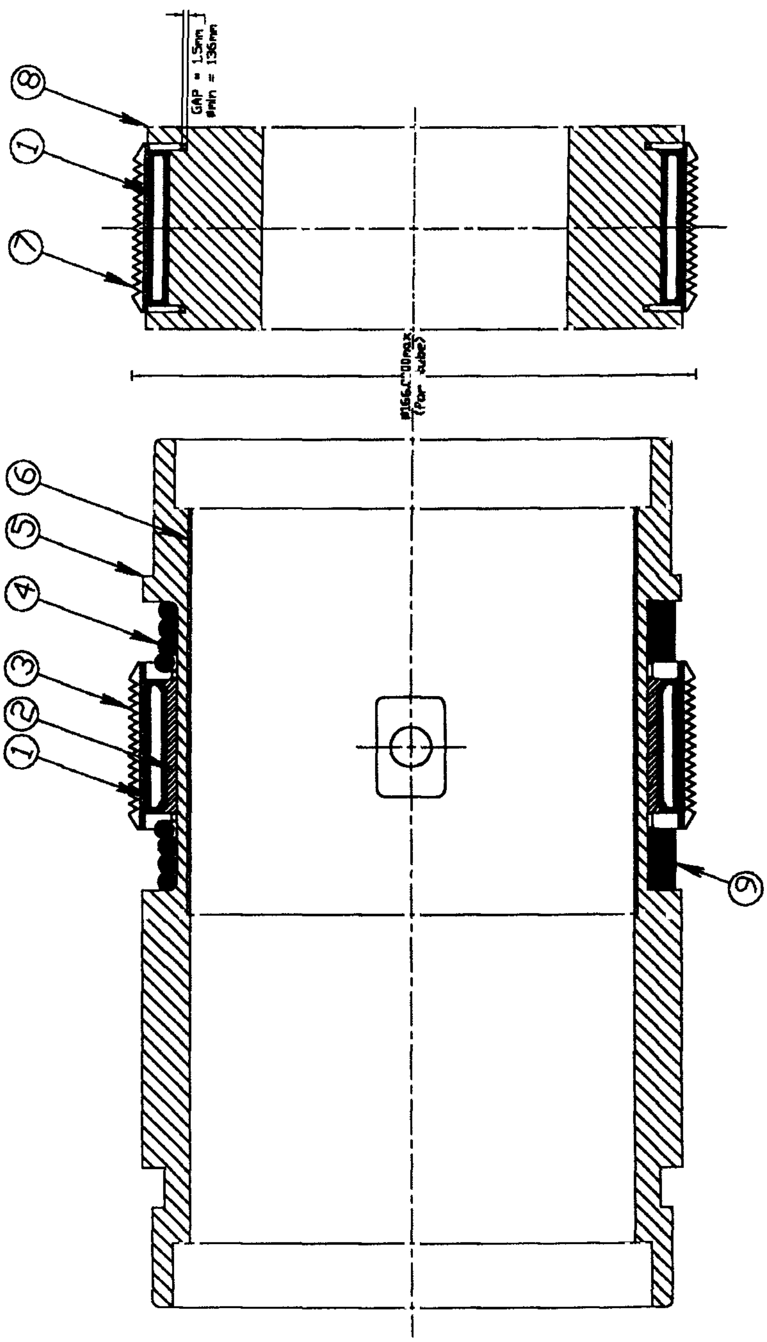

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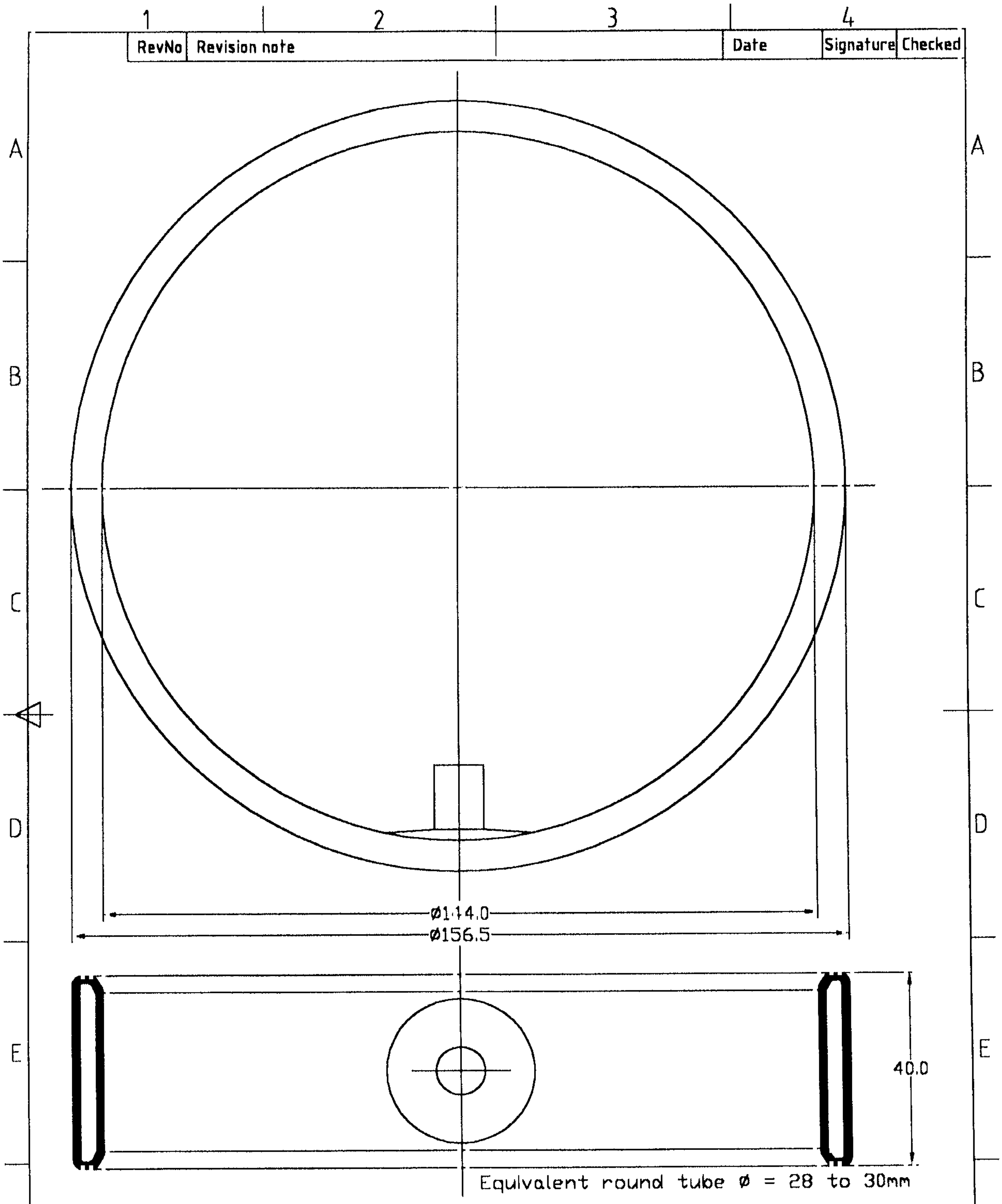

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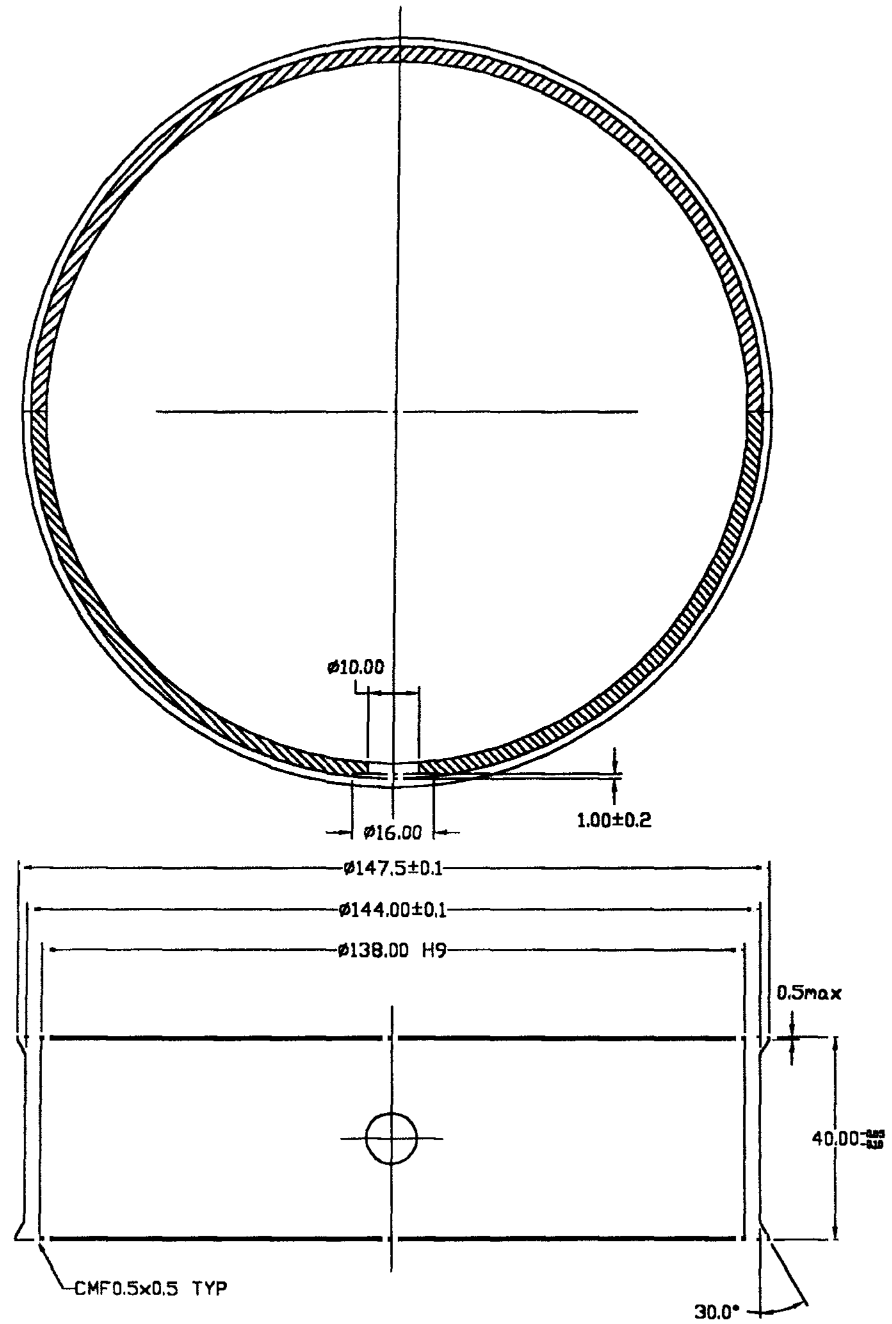

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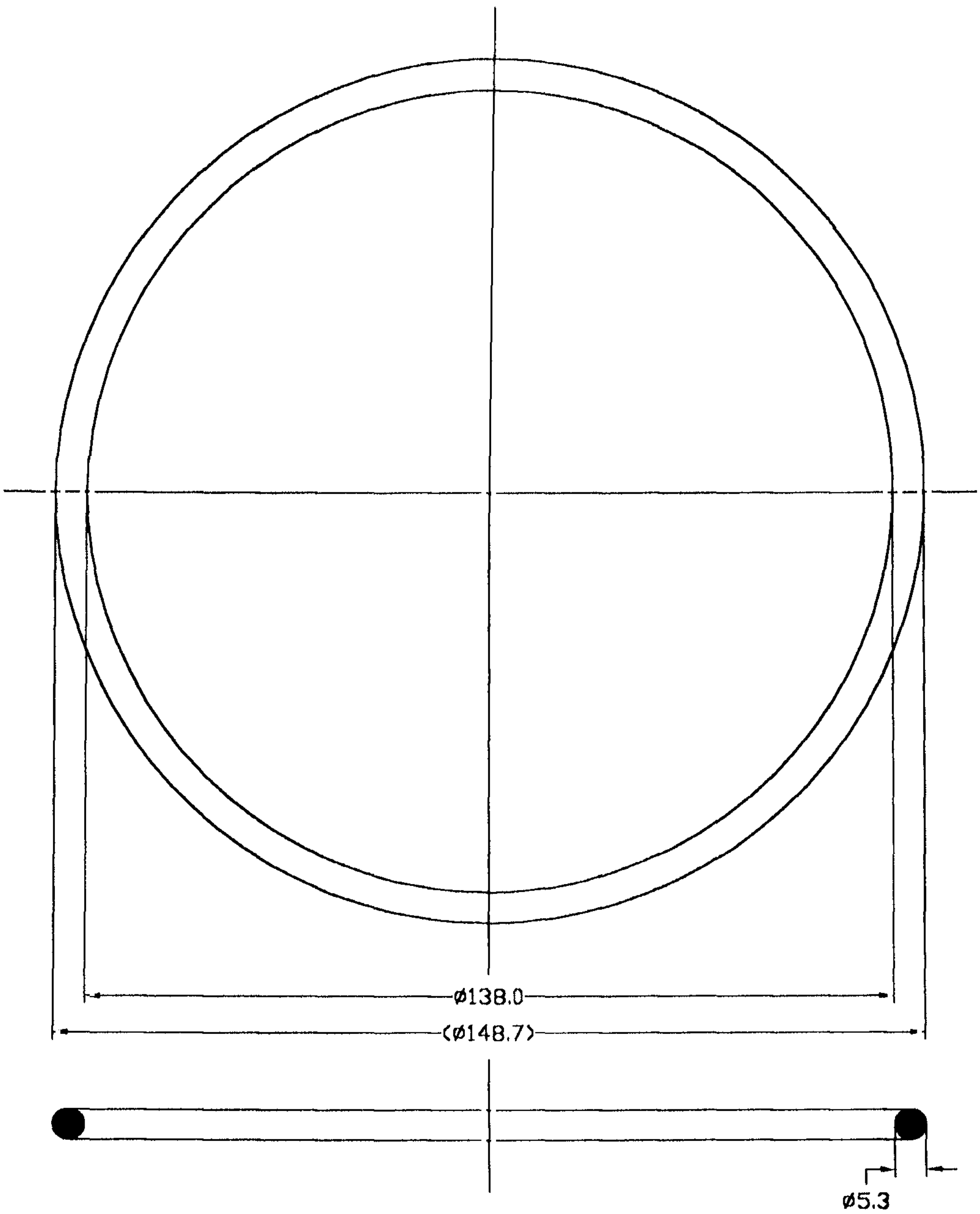

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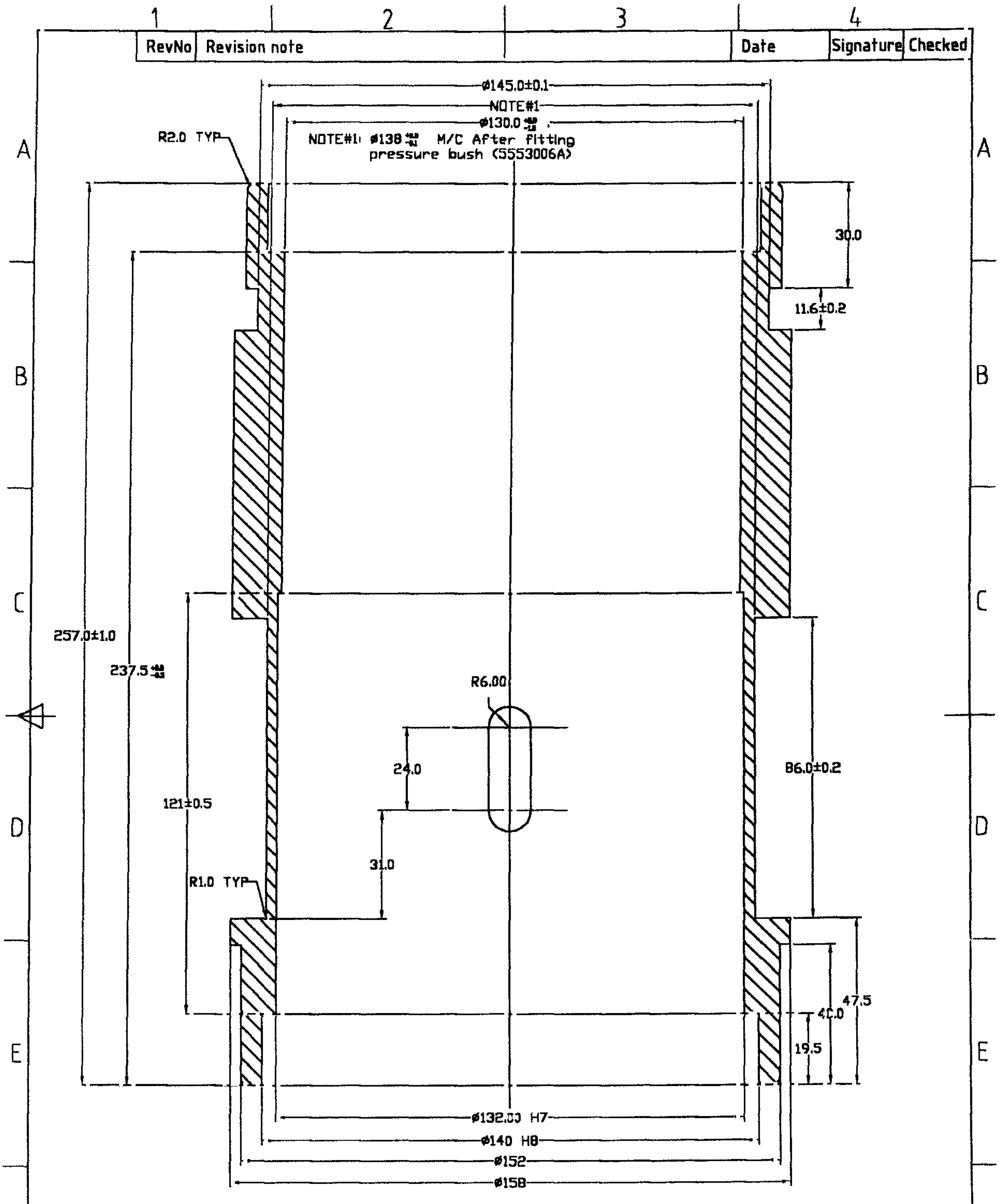

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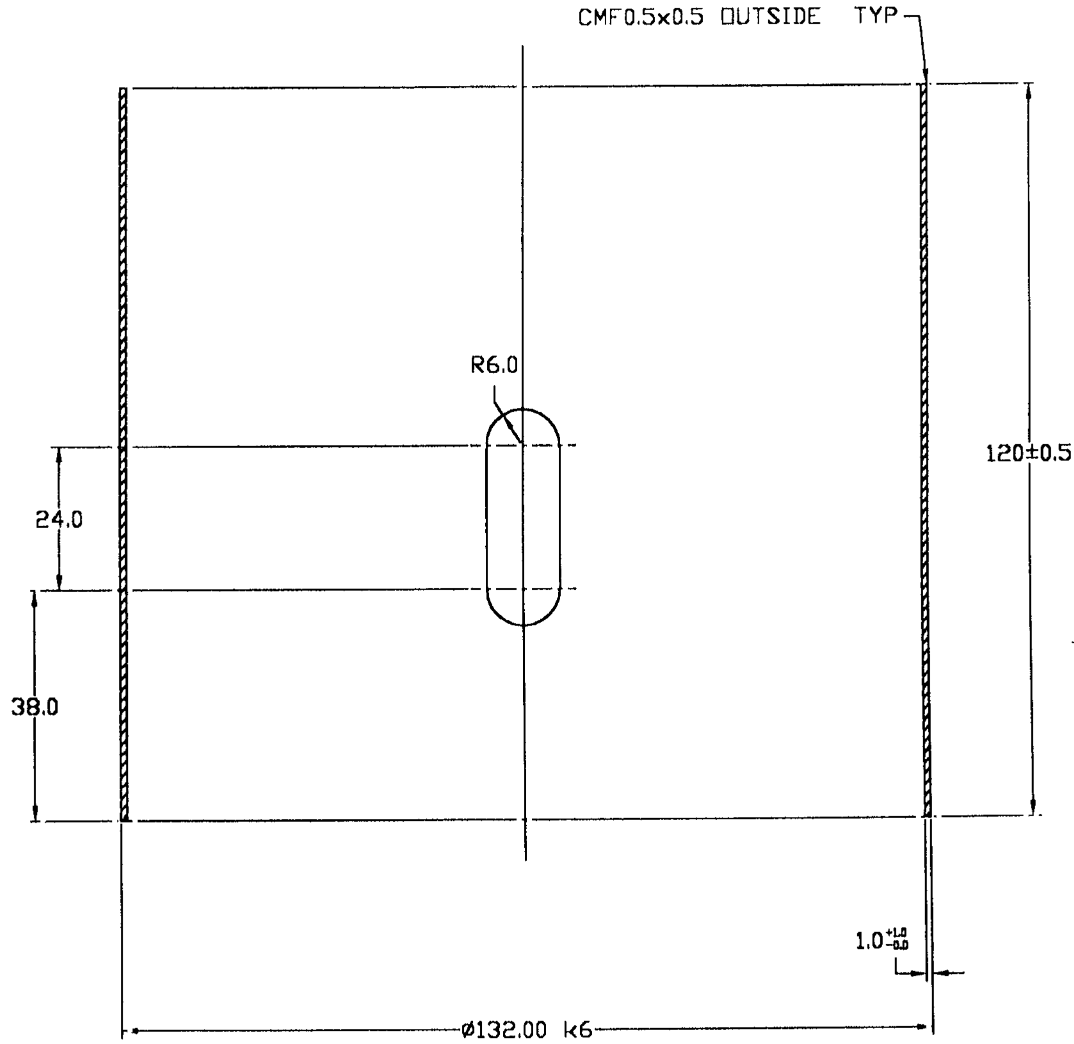

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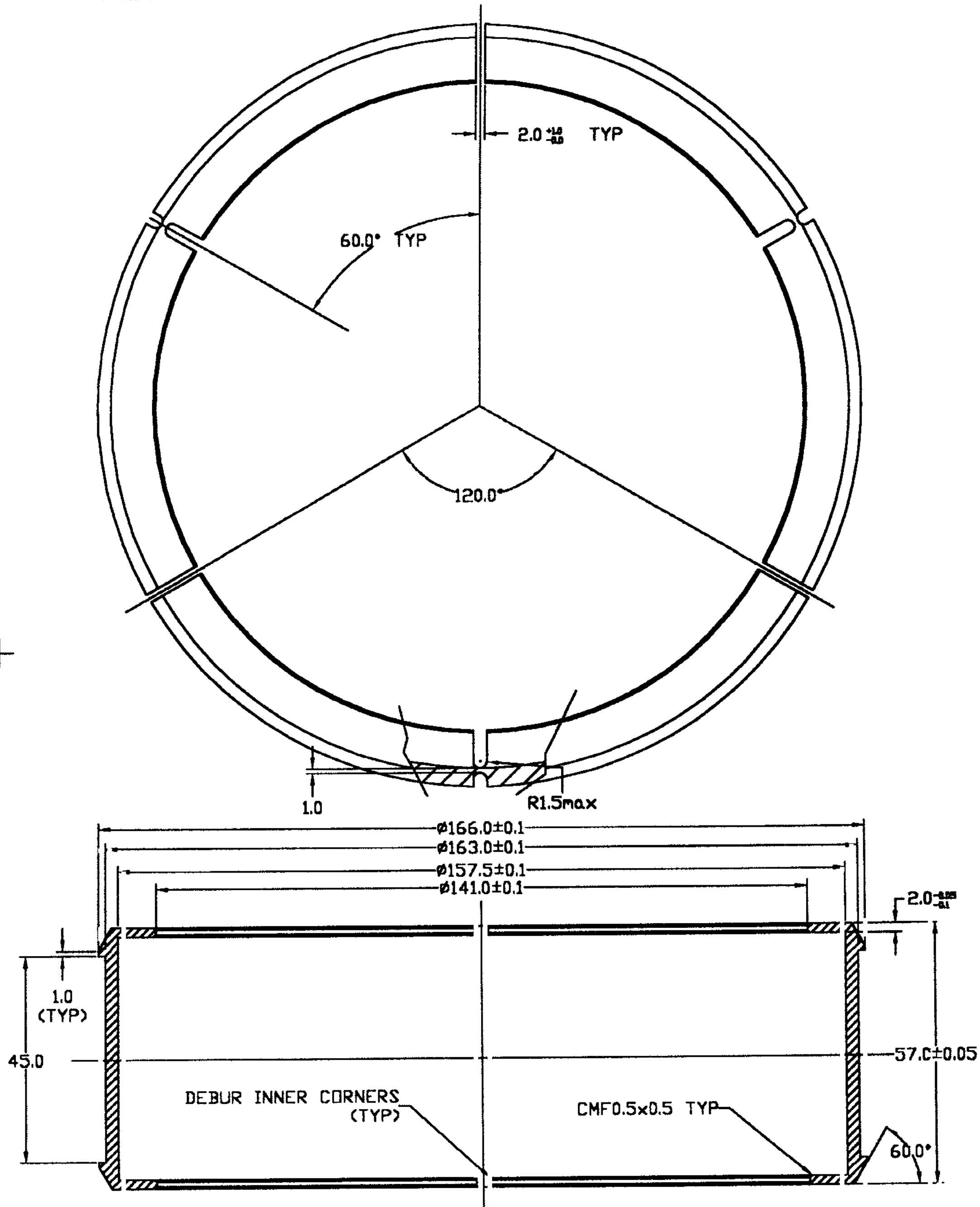

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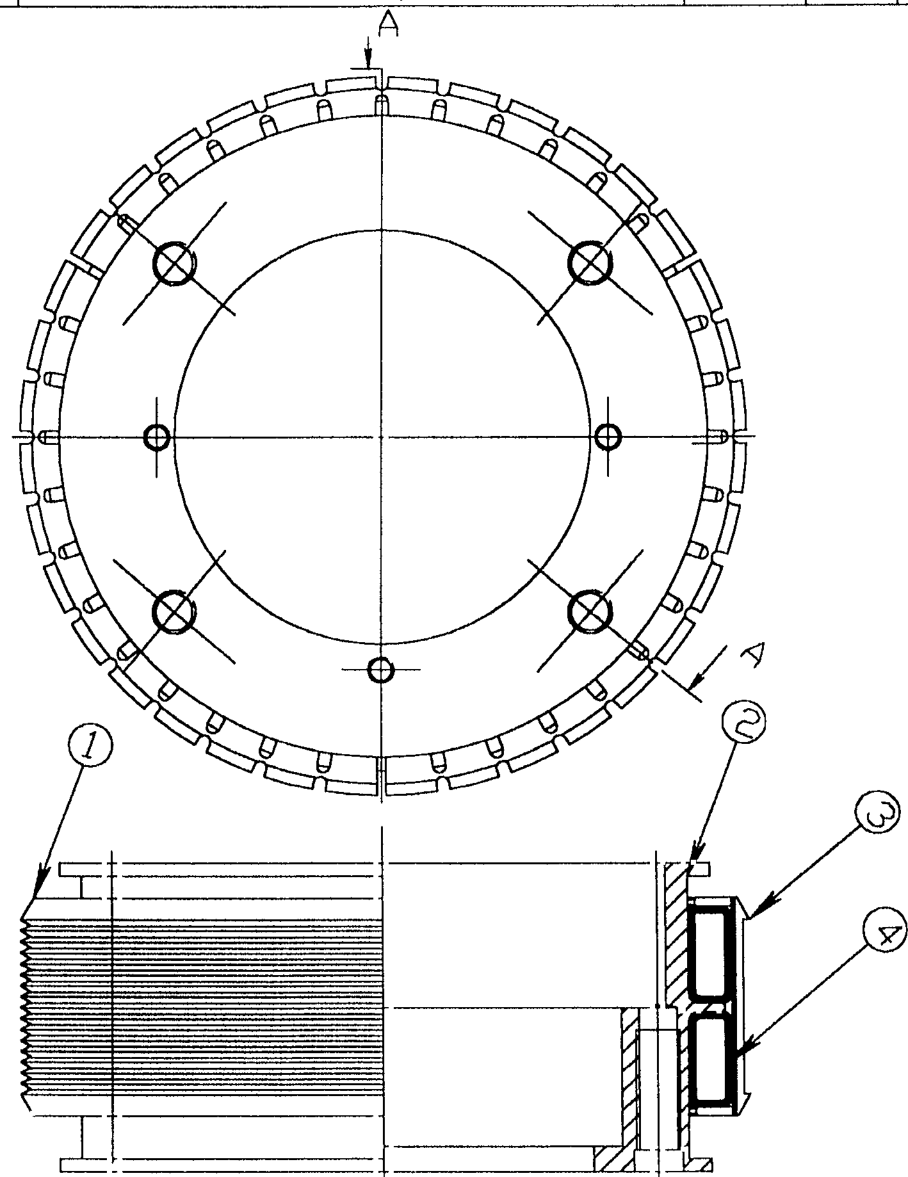


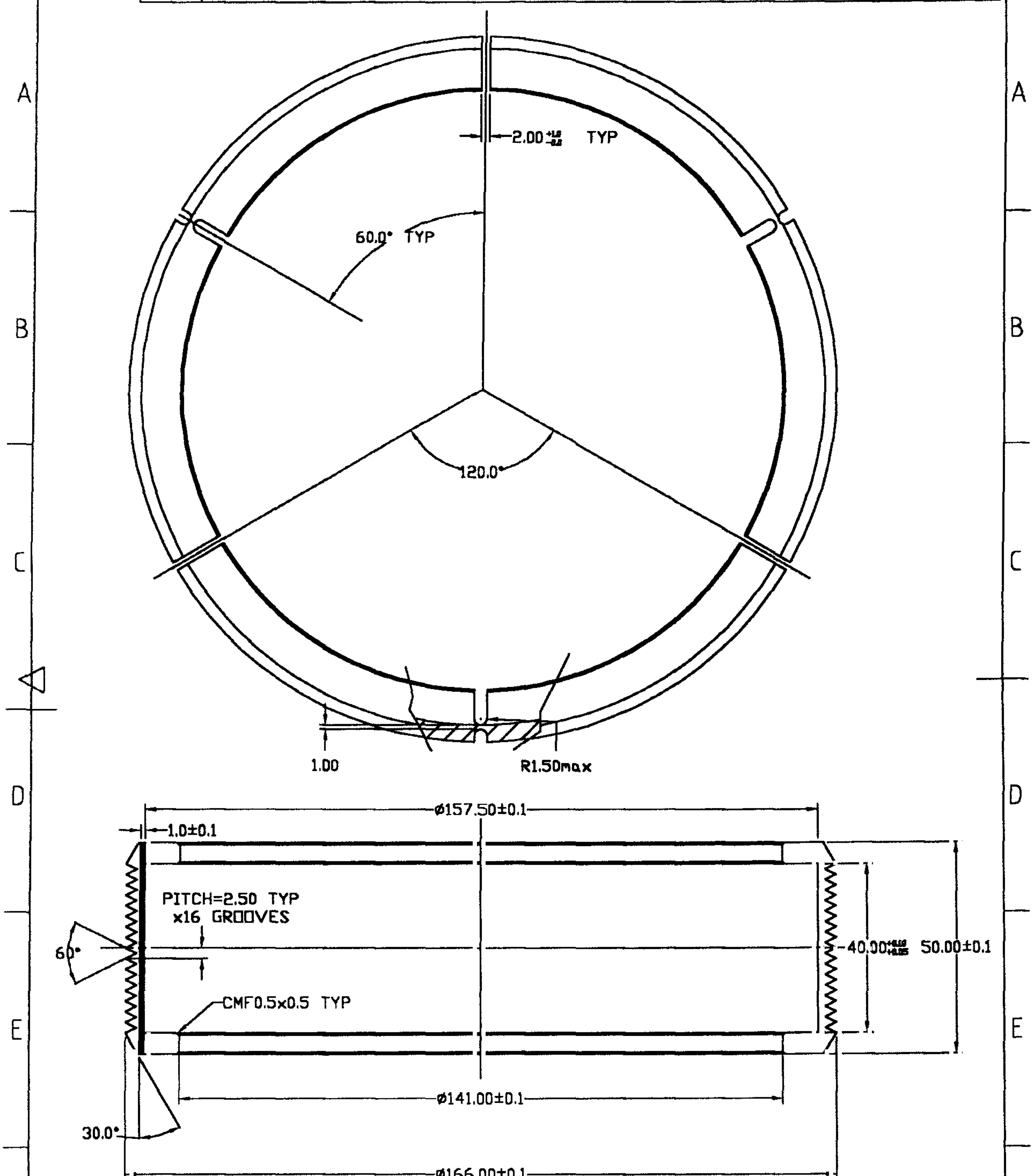
VIEW AA

ITEM NO	DISCRIPTION	QTY.	DRAWING NO
4	FRONT BRAKE TUBE	2	5553010A.DWG
3	FRONT BRAKE SHOES #3	1 (x3)	5553007C.DWG
2	FRONT BRAKE RING	1	5553008D.DWG
1	FRONT BRAKE SHOES #2	1 (x3)	5553007B.DWG

Designed by	Checked by	Approved by - date	Filename	Date	Scale
J.MAAREN	T.SCANLON	10/06/97	5553802B.DWG	10/06/97	NTS

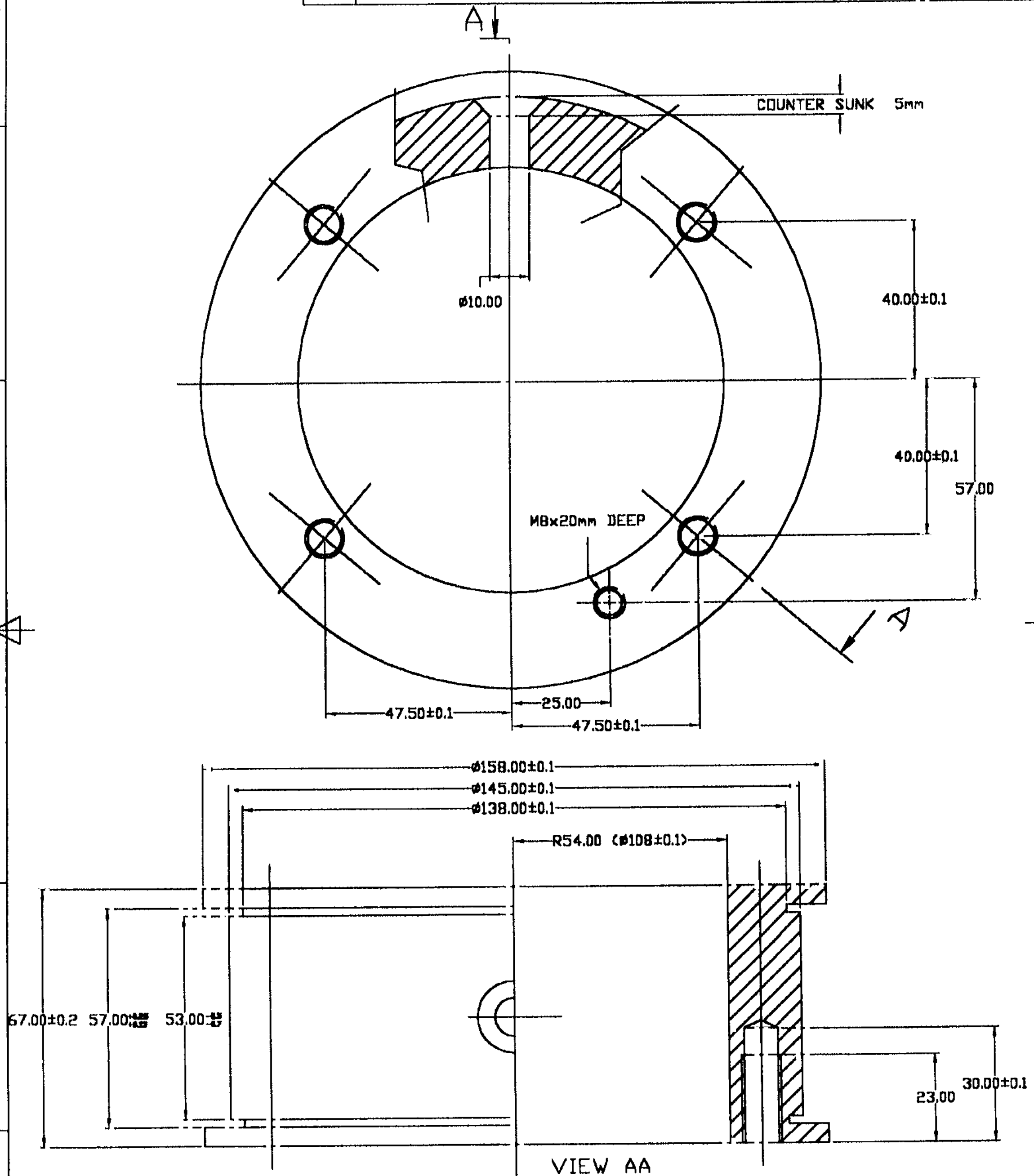
CSIR	FRONT_BRAKE_ASS		
	5553802B	Edition 1	Sheet 6/6

RevNo	Revision note		Date	Signature	Checked

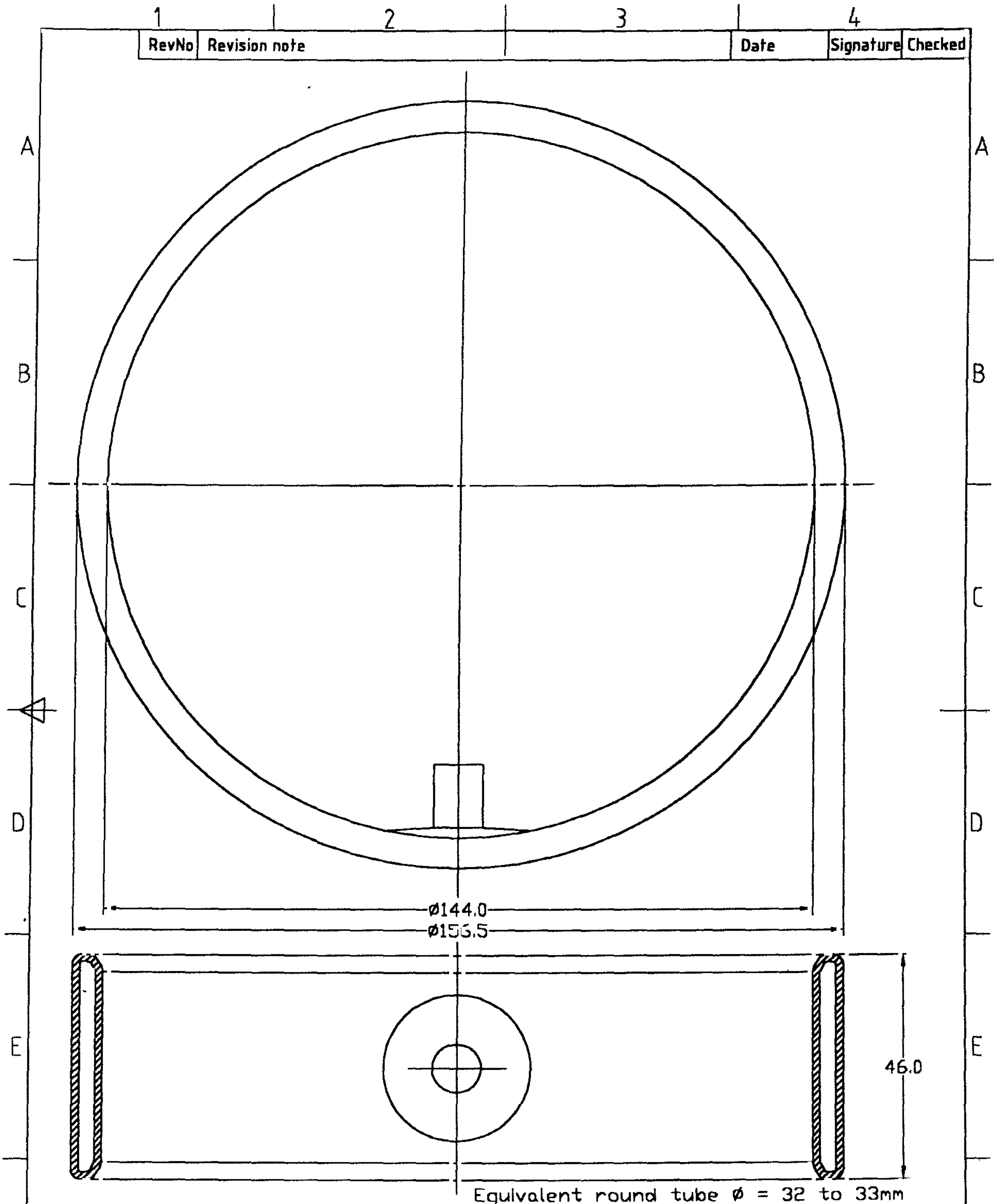


Quantity :1 (x3)	Material :Mild Steel				
Designed by J.MAAREN	Checked by T.SCANLON	Approved by - date 09/06/97	Filename 5553003A.DWG	Date 06/06/97	Scale NTS
CSIR		REAR_BRAKE_SHOES			
		5553003A		Edition 1	Sheet 4/9

RevNo	Revision note	Date	Signature	Checked
008A	ORIGINAL DESIGN	05/06/97		Checked
008B	REVISED DESIGN - MASS REDUCTION	09/06/97		Checked
008C	REVISED DESIGN - INCREASED INDUCED DAMPING	09/06/97		Checked
008D	REVISED DESIGN - EASIER MANUFACTURING	10/06/97		Checked
008E	REVISED DESIGN - EASIER MANUFACTURING	11/06/97		Checked

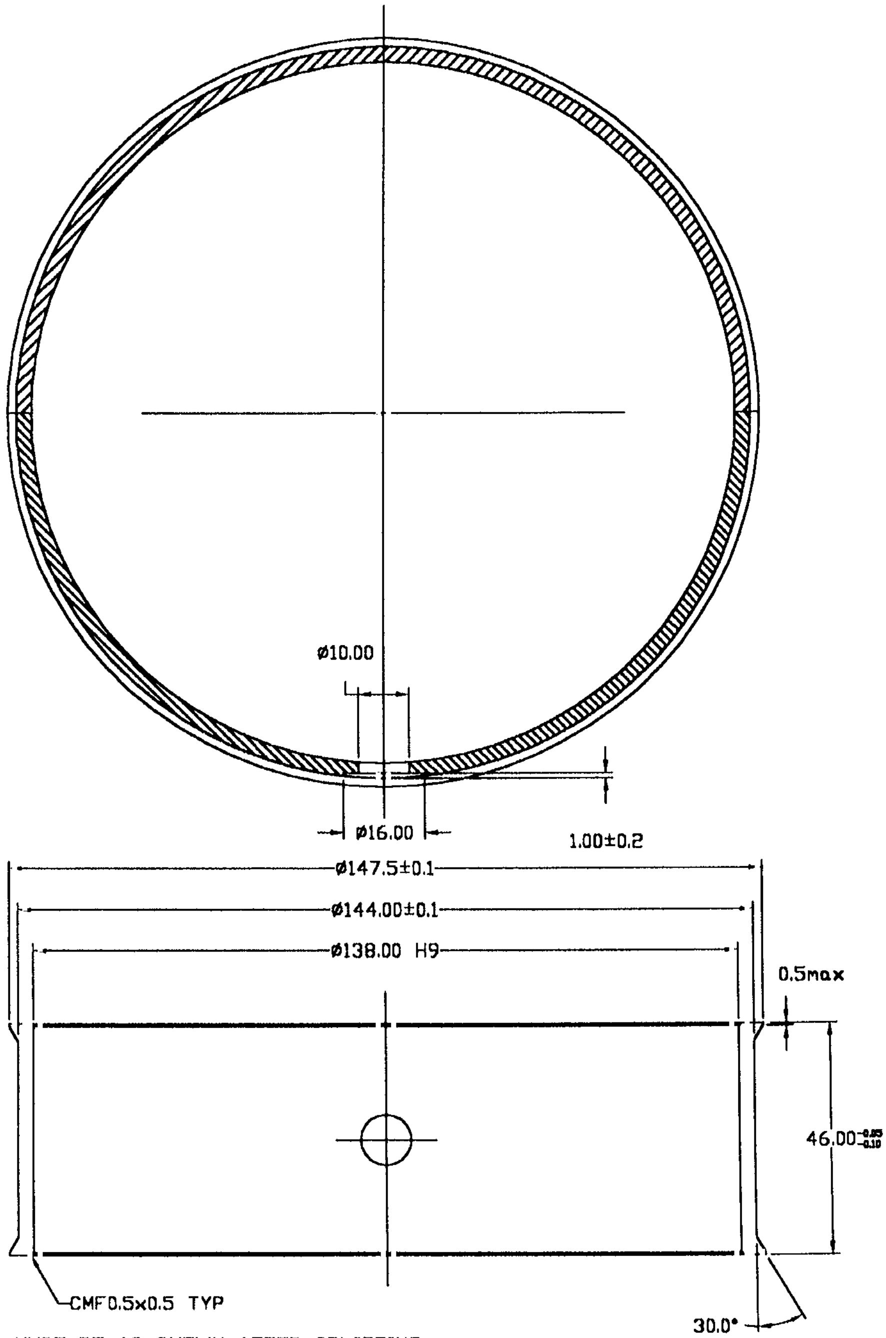


Quantity :1	Material :ALUMINIUM				
Designed by J.MAAREN	Checked by T.SCANLON	Approved by - date 24/07/97	Filename 5553008G.DWG	Date 24/07/97	Scale NTS
CSIR	FRONT_BRAKE_RING				
	5553008G			Edition 1	Sheet 8/9



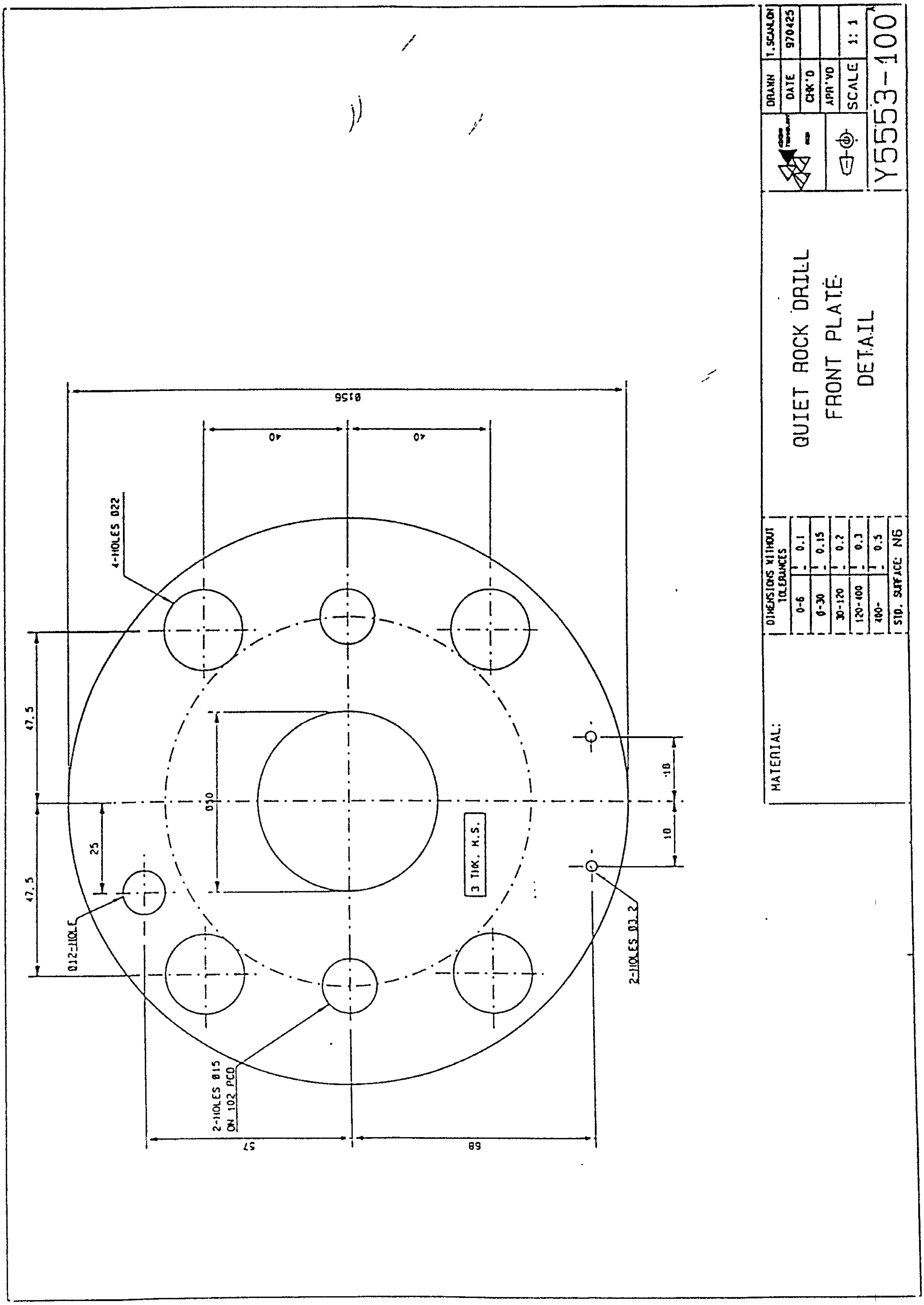
Quantity :1	Material : RUBBER				
Designed by J.MAAREN	Checked by T.SCANLON	Approved by - date 11/06/97	Filename 5553010B.DWG	Date 11/06/97	Scale NTS
CSIR	FRONT_BRAKE_TUBE				
	5553010B			Edition 2	Sheet 5/5

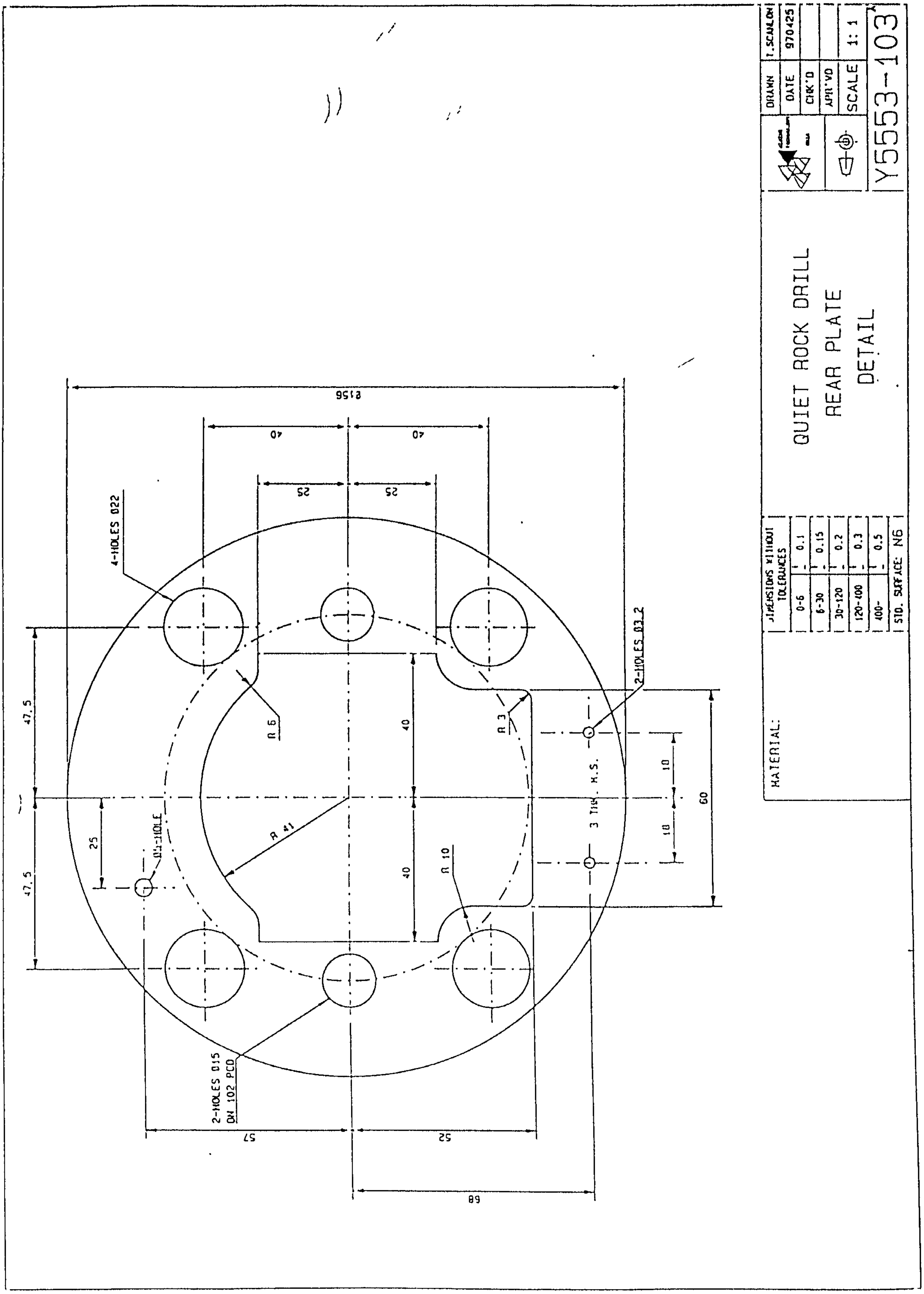
RevNo	Revision note	Date	Signature	Checked

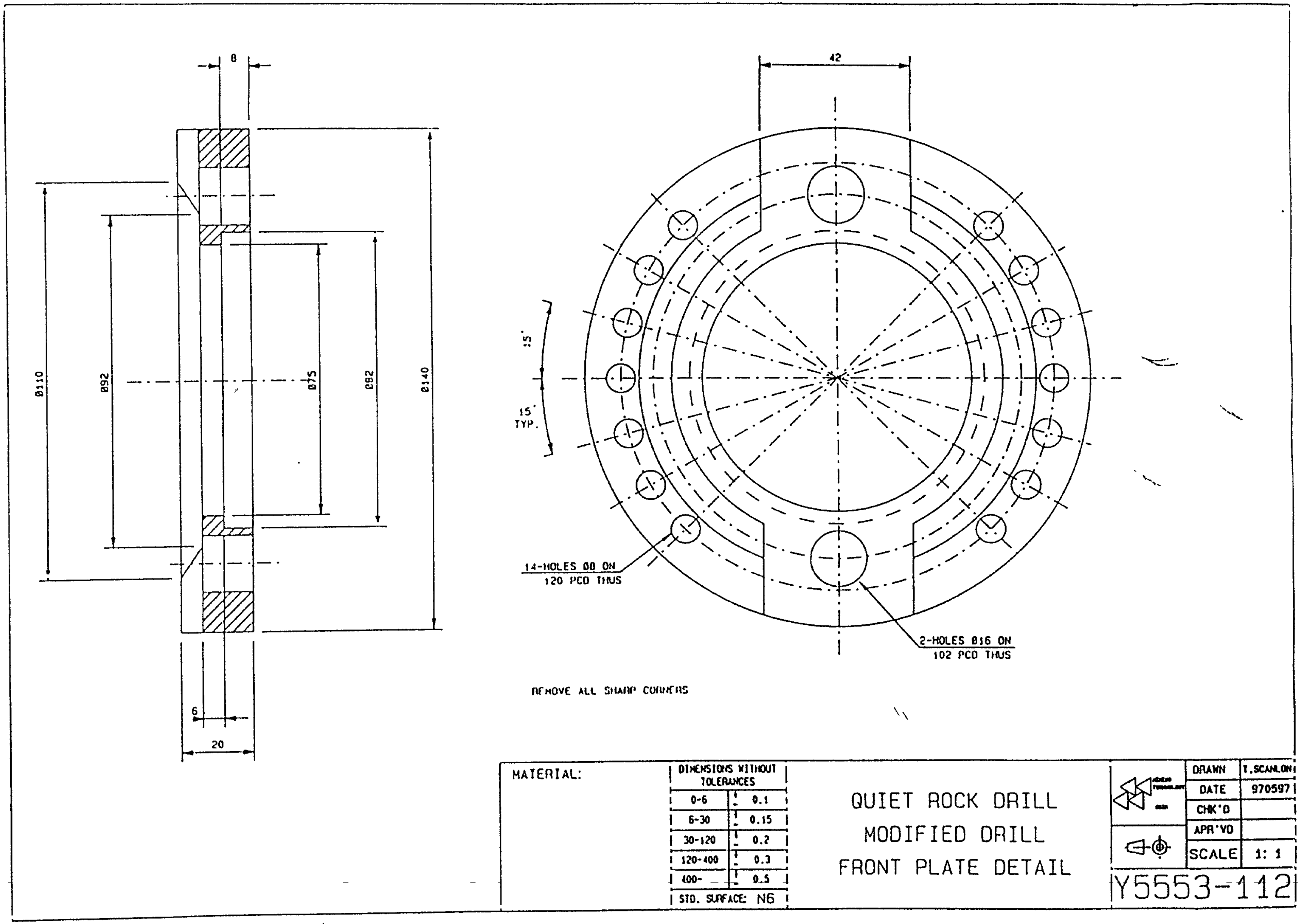


NOTES:
DIMENTIONS MUST BE AS SHOWN AFTER SPLITTING.

Quantity :1		Material :Mild steel			
Designed by J.MAAREN	Checked by T.SCANLON	Approved by - date 11/06/97	Filename 5553012A.DWG	Date 06/06/97	Scale NTS
CSIR		FRONT_BRAKE_SLIDE			
		5553012A		Edition 2	Sheet 2/5

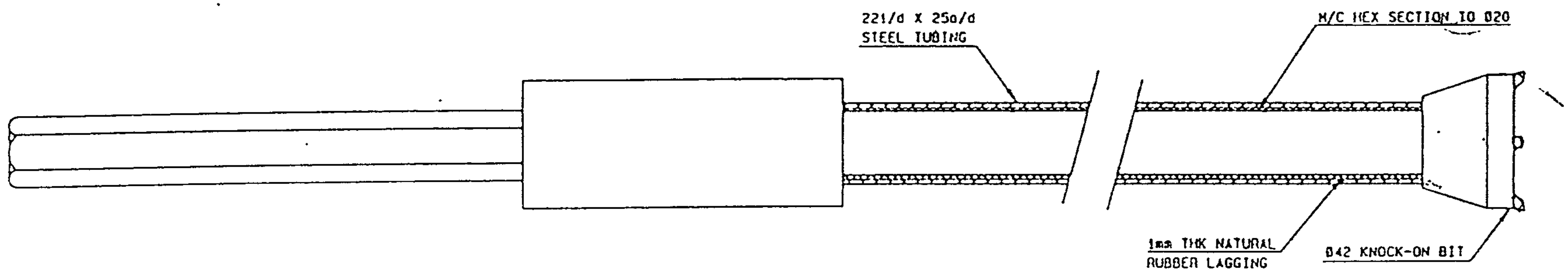

QUIET ROCK DRILL
FRONT PLATE
DETAIL
Y5553-100
DRAWN T.SCANLON
DATE 970425
CHK'D
APR'VD
SCALE 1:1
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE: N6
4-HOLES Ø22
2-HOLES Ø15 ON 102 PCD
Ø12-HOLE
2-HOLES Ø3.2
3 THK. M.S.
Ø156
40
40
47.5
47.5
25
Ø50
10
10
57
68


QUIET ROCK DRILL
REAR PLATE
DETAIL
Y5553-103
DRAWN T.SCANLON
DATE 970425
CHK'D
APP'VD
SCALE 1: 1
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE N6
4-HOLES Ø22
2-HOLES Ø3.2
2-HOLES Ø15
ON 102 PCD
R 6
R 3
R 10
R 41
Ø156
40
40
25
25
47.5
47.5
60
10
10
57
52
68


8
Ø110
Ø92
Ø75
Ø82
Ø140
6
20
42
15°
15°
TYP.
14-HOLES Ø8 ON
120 PCD THUS
2-HOLES Ø16 ON
102 PCD THUS
REMOVE ALL SHARP CORNERS
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE: N6
QUIET ROCK DRILL
MODIFIED DRILL
FRONT PLATE DETAIL
DRAWN T.SCANLON
DATE 970597
CHK'D
APR'VD
SCALE 1: 1
Y5553-112

7.3 Appendix C Drill steel modification drawings

This appendix includes the drawings detailing the modification to the drill steel to effect noise damping.



MATERIAL:

DIMENSIONS WITHOUT TOLERANCES	
0-6	± 0.1
6-30	± 0.15
30-120	± 0.2
120-400	± 0.3
400-	± 0.5
STD. SURFACE: N6	

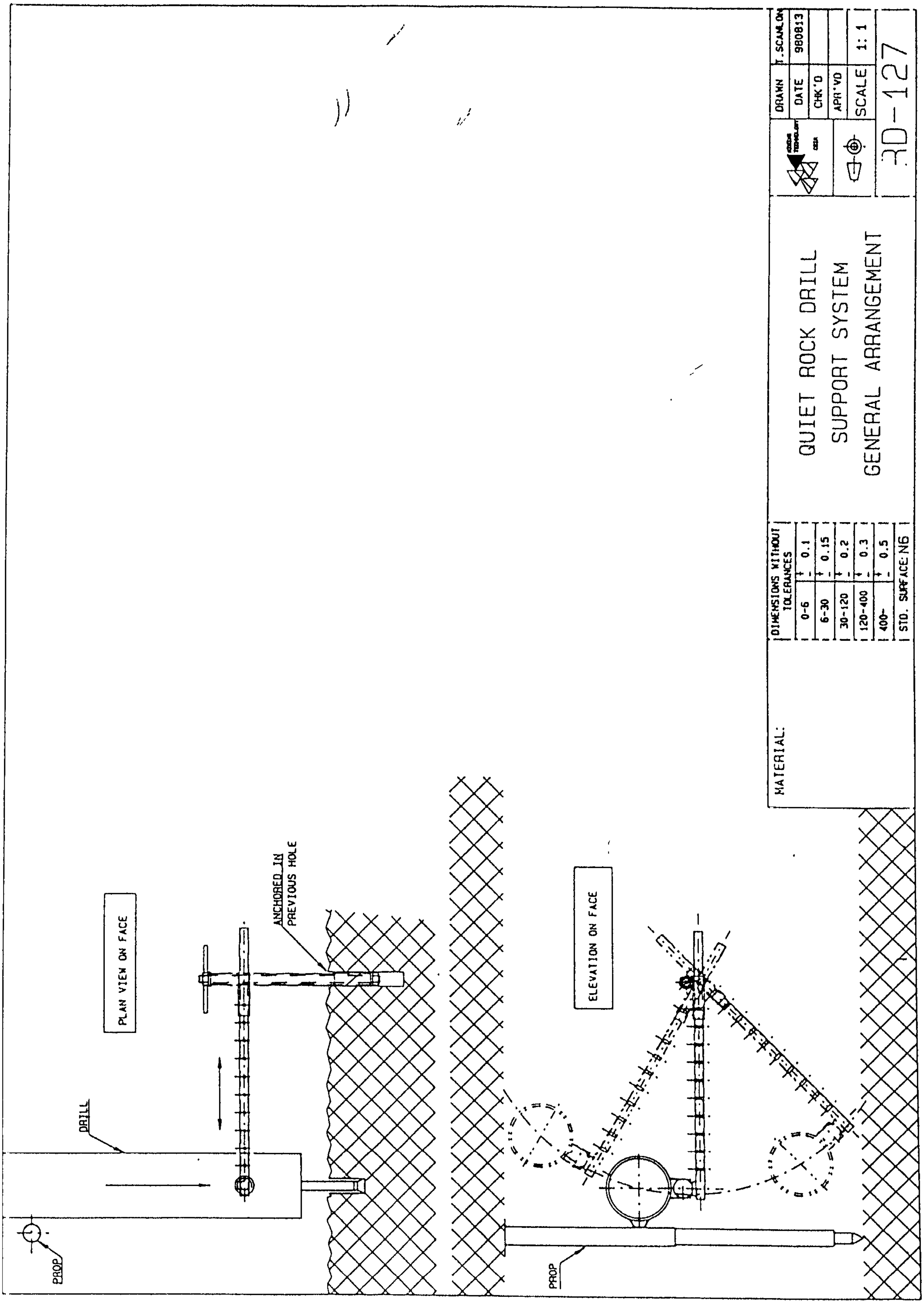
QUIET ROCK DRILL
AIR THRUSTED
MODIFIED DRILL STEEL

DRAWN	T.SCANLON
DATE	971204
CHK'D	
APR'VD	
SCALE	1: 1.5

RD-045

7.4 Appendix D Stinging arrangement drawings

This appendix includes the drawings of the stinging and support elements used during surface testing of the prototypes.


QUIET ROCK DRILL
SUPPORT SYSTEM
GENERAL ARRANGEMENT
DRAWN T.SCANLON
DATE 980813
CHK'D
APR'VD
SCALE 1:1
3D-127
MATERIAL:
DIMENSIONS WITHOUT TOLERANCES
0-6 ± 0.1
6-30 ± 0.15
30-120 ± 0.2
120-400 ± 0.3
400- ± 0.5
STD. SURFACE: N6
PLAN VIEW ON FACE
ANCHORED IN PREVIOUS HOLE
DRILL
PROP
ELEVATION ON FACE
PROP