7 Reaming Drilling Techniques of Hard Crystalline Rock

The main problems encountered in the reaming drilling of CCSD-1 Well were as follows:

1. Hard formation was difficult for drilling: according to the cores recovered from the pilot hole drilling, the formation encountered by reaming drilling was crystalline rock (mainly eclogite and gneiss), with drillability grades of 8–9 in most cases, the major was grade 9, and the drillability of a few rocks was even up to grade 10–11, and the penetration rate per hour was lower. If diamond reaming bit was to be used, since low rotary speed of the rotary table, the penetration rate would be very low; while using rock bit (mainly with volumetric fragmentation form) to ream the hole would still lead to low penetration rate since the serious bit bouncing and rough drilling and the bit pressure couldn't be exerted to the drill bit.
2. Serious bit bouncing would happen: according to the geological information obtained from the pilot hole drilling, the rock properties of the formation to be drilled were hard and brittle, and a great amount of broken zones would be penetrated through, with soft and hard interbedded formations. When rock bit was used to ream hole, the hole bottom shape was irregular, which was easy for rock bit to bounce in the process of rolling, and in the meantime, the rock bit was frequently obstructed by broken face of the rock in the process of rotation in the hole and thus the drill bit was easy to bounce, so that the drilling tool and the drill bit would bear larger impact load over a long period of time, very easily resulting in fatigue and damage for the drilling tool and the drill bit, being detrimental to drilling safety.
3. Rock blocks could frequently fall from hole wall: the formation rocks to be drilled were very hard and broken, rock blocks often fell off from the hole wall, the rocks had no permeability, very difficult for drill mud to form mud cake to effectively protect hole wall, and thus the unstable rock in the hole wall was in a free state; the releasing of the crustal stress in the formations promoted the new fracture to form and the unstable rock block to fall after the hole wall was produced; in the process of drilling, the bouncing of the drilling tool could produce disturbance and beat to the hole wall, easily causing rock broken and falling. Since the fallen rock has high hardness and strength, drilling tool sticking would very easily happen.
4. Drilling tool could wear seriously: the rock drilled is crystalline rock, contains a lot of quartz minerals and thus has high hardness and very high abrasiveness. Under these circumstances the side face of the pilot bit body, the outer and gauge teeth of rock bits, the leg gauge and bit gauge, the stabilizers, the reamers, the collars and so on, would be worn off very seriously, leading to a lower bit footage, shorter bit service life, the undersized hole diameter and hole accidents. Since the drill bit wore quickly, the hole section drilled by each drill bit would obviously become conical, when a new drill bit was changed in the process of drilling, much time was needed to drill off, and it was easy for the hole to become a wedge shape and thus the drilling tool be stuck. This drilling tool sticking or drill bit deformation was detrimental to hole safety.
5. Threat from falling objects: in the process of drilling, pilot body, tools, cones, tungsten carbide inserts and other objects would probably fall into the hole. These falling objects could easily produce an obstruction to the drilling tool in the process of drilling and stick the bit cones and the bit pilot body so that drilling couldn't normally advance, and also would bring a great threat to safe reaming drilling.

7.1 Development of Pilot Reaming Bits

The rock bits for oil drilling are mainly used for softer sedimentary rocks, precedents that the rock bits used for reaming drilling in so hard rock have seldom been found.

Translated by Zhang Yongqin.

D. Wang et al., *The China Continental Scientific Drilling Project*,
Springer Geology, DOI 10.1007/978-3-662-46557-8_7

The conventional reaming rock bits have a poor adaptability to the rock formations in this drilling project. At the same time, the hole size designed for this drilling project was special, and there was no any standard rock bit size both at home and abroad, so specially designed reaming rock bits were needed. Since the assembled rock bit was adopted, the welding strength for combination, the type option of the cone and the arrangement of the cones etc. still needed further study, and the load exerted to the bit pilot body and the strength design were one of the main difficult points. The state of force borne by the cone bearings of the pilot reaming drilling was different from that of the conventional non-core drilling, when the rock fragmentation ring was narrow, the direction of the axial force of cone bearings would be changed, the axial outward force was smaller and easily caused cone falling.

Some problems that needed to be solved in the application of the reaming rock bits were as follows:

1. The abrasiveness and impact resistance of the cutters: since the rock formation was hard, broken and highly abrasive, the main requirements to the bits included the abrasiveness of the bit cutters so that a longer service life and a higher drilling speed could be guaranteed. At the same time, because of frequent bouncing of the drilling tool in the process of drilling, the teeth would break off as the single cone or tungsten carbide cutter bore a tremendous load instantaneously.
2. Bit gauge protection: poor gauge protection would lead to a decrease of the hole diameter as the drill bit worn and that could cause an increase of drilling-off work when a new drill bit was used in the next roundtrip, easily leading to a wedge-shaped sticking of the drilling tool in the meantime, and thus bringing serious damage to the follow-up drill bits.
3. Bit strength: drill bit would bear large impact load because of hard and broken rock formations and the falling rock blocks and other falling objects. In the process of design and manufacture of the drill bit, it would be necessary to prevent the deformation, breaking-off, falling-off of the cone or the pilot body from the drill bit so that in the hole accidents would be avoided.
4. Good pilot performance: since the rock formations were broken, the problems of soft and hard non-homogeneous formations may probably exist. For the sake of preventing deviating from the axel line of original hole drilled as the pilot hole in the process of reaming drilling, a good pilot ability of the pilot drill bit would be needed, the long pilot body would have a good pilot ability, however, it would bear bigger torque. A high strength pilot body was needed.
5. Rock fragmentation of pilot bit: to avoid protruding rocks, falling rock blocks or broken debris in the small diameter pilot hole, the end face of the pilot bit body would have rock cutting ability in order to avoid the obstruction to the drill bit and non-advancing.
6. The abrasiveness of pilot body: since the reaming drilling was to be carried out in the φ 157 mm hole which had been completed before, and during core drilling φ 89 mm drill rods and φ 120 mm collars were used and when reaming drilling φ 127 mm drill rods and φ 177.8 and φ 203.2 mm collars were used, so the rigidity of the two drilling tools was different. Because the rigidity of the drilling tool in the process of reaming drilling was bigger, after assembling the stabilizer which coincided with axel line of the pilot hole, the drilling tool assembly produced a bending and made the down-hole drilling tool bear bigger bending moment, easily causing the problems of drilling tool bouncing and sticking, big friction obstruction during pulling-up and running-in, wearing of the bit pilot body, etc. Wear of the pilot body would decrease its diameter and cause φ 311.1 or φ 244.5 mm drill hole deviating from φ 157 mm pilot hole axis line. Under these circumstances the afterward run-in bit pilot body would bear bigger bending moment and damage very easily. However, if the rigidity of the reaming drilling tool was too low, the strength of the drilling tool would be low and the hole dog-leg angle would be big, and then leading to a difficulty to run casing.

In order to meet the urgent demands of the drilling project, the CCSD-1 headquarters cooperated respectively with the Institute of Exploration Techniques and the Jianghan

Fig. 7.1 KZ Series of rock bit developed by IET

Fig. 7.2 KHAT series of rock bit developed by Kingdream

Kingdream Engineering Drilling Tool Company to research and manufacture the KX and KHAT types of the reaming drilling bits. The reaming drilling bits used in CCSD-1 reaming drilling were just these two types (Figs. 7.1 and 7.2).

7.1.1 KZ157/311.1 Type Reaming Bit

1. **Design and Improvement of KZ157/3111.1 Type Reaming Bit**
   (1) Option of the bit cutter

Cone tooth breaks the rock in ways of impact, indentation and shearing; in hard rock formations these fragmentation ways can produce volumetric fragmentation effect, especially in reaming drilling phase. Since the free surface of the slim hole had been produced, under the action of the impact way, the free surface can be effectively used and big volumetric fragmentation effect can be produced. Rock bits are widely used in oil drilling industry and are very perfect; in comparison with other cutters rock bits have the advantages of long service life and high drilling speed. If diamond drill bit was used for drilling, the cutting volume per revolution would be very little and high revolution would be needed for cutting, which just was what the rotary table drill rig at the drill site couldn't satisfy. If the PDC bit was used, and then since the rock formation was extremely hard, it would be difficult for the cutters to cut into the rock formation and the scraping effect couldn't be realized, the non-homogeneousness of the rock formation could also lead to PDC cutter breaking in the process of revolution because of the impact load.

The load bearing state of drill bit cutters in reaming drilling was very bad, so the bigger diameter bit leg would be needed as far as possible. But if the bit leg was too big, it would affect the cross-section area for connection between the bit pilot body and bit body and thereby further affect the bit strength.

The reaming drilling bits can be made into tri-cones, four cones, six cones and so on. The stability of four-cone reaming drilling bit is poor and easily vibrates in drilling. The stability of tri-cone bit and six-cone bit is good, but if the number of the cone is much more and the bigger bit leg is selected in a limited arrangement space, it will irresistibly affect the connecting strength between the pilot body and the bit body and it will be detrimental for increasing the cutter and bit body strength.

The KZ reaming drilling bit used the cone leg of the φ 215.9 mm insert rock bits as the cutters, φ 215.9 mm insert rock bit is the most common bit size in petroleum drilling industry, with the cone cutters perfectly developed. The bearings of the rock bit have the pressure-balance lubrication system and is suitable for the deep well drilling; the cone bearings use the metal floating sealing as the sealing structure, with very good performance; the ability against the impact load is very strong and is suitable for high linear velocity drilling; the spare part models are all ICDC537 and 547 (or equal to 537 and 547), the blade height of the tungsten carbide cutters is not high, with better toughness, not easy to break off under higher impact load when drilling in hard rock formations. The arrangement of tungsten carbide teeth on the cone is closer, the outer diameter teeth and gauge protection teeth are strengthened, and this arrangement of the cutter teeth is suitable for drilling in highly abrasive crystalline metamorphic rock (eclogite, gneiss). The bit leg used tungsten carbide to strengthen the gauge protection and to increase the abrasiveness resistance of the leg.

(2) Enhancing the integral strength of the bit

An integral structure design (Fig. 7.3) was used for drill bit. The bit body, the large diameter stabilizer and the extended pilot-body were integrated and had high strength; forged low-carbon alloy steel, which was tempered in heat treatment, was selected for the material for main bit body.

In the early time, 35CrMoA high strength alloy steel was selected for the bit body. Although the weldability of 35CrMoA steel was acceptable, it couldn't meet the demands

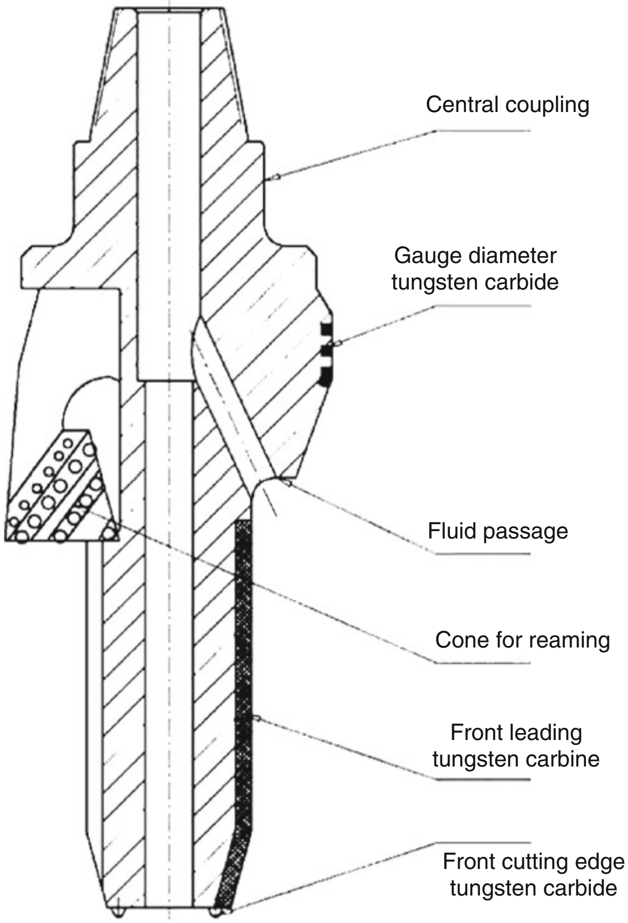

Fig. 7.3 The structure scheme of KZ reaming bit

in practical drilling. In the process of drilling operations, since the formation was brittle and broken so that an irregular hole bottom would be easily formed, which made a single cone leg bearing the impact load of the whole drilling tool instantaneously, and thus the welding seams frequently fractured. Among the drill bits used in drilling applications, KZ157/311-05 bit deformed after the welding seam fractured in drilling, the bit deformed, the drilling tool was stuck in the hole, and when the drilling tool was pulled up with strong force, two bit legs fell off in the hole bottom. Although some improvement methods were taken, such as preheating, heat preservation, increase of welding slope slot and welding seam height and use of high strength welding rod, the problems of welding seam breaking still frequently occurred.

In the later period, a batch of forged low carbon steel 20CrNiMoA was ordered as the bit material from a special steel plant, and its weldability and welding strength were obviously improved. After the new material was used, the welding seam between the bit leg and the bit body never broke again, the problem of welding seam strength was solved and then the welding reliability of the bit was ensured.

(3) Enhancing the bit pilot performance

The bit used its steel body as the pilot, which was 350 mm long at the beginning. In order to further decrease the turning torque of the drilling tool and the breaking of the pilot body, the effective length of the pilot body was reduced to 250 mm subsequently. Tungsten carbide was inserted onto the outer cylindrical surface of the pilot section and thus the wear-resistance was increased. Then the drill bit had a good and stable pilot performance in a long term.

In order to prevent larger rock blocks from falling off into φ 157 mm pilot hole during reaming drilling, a tungsten carbide bit or tri-cone rock bit was designed in the front end of the pilot body as the pilot bit.

The pilot bit with the inserted tungsten carbide cutters: the tungsten carbide cutters were integrated with the bit body, i.e., high blade tungsten carbide cutters were coldly inserted onto the lower end of the pilot body; the cutters could clean up or break the falling blocks simply. The strength of this bit was weaker and the cost was lower, therefore, this bit structure was mainly used in reaming drilling.

The cone pilot bit: a 152.4 mm rock bit was jointed in the lower end of the pilot body (Fig. 7.4), with the main purpose to clean up the settlings in the pilot hole bottom, such as the tungsten carbide and the collapsing rocks from the pilot hole wall. This structure was mainly used for the final three reaming drill bits.

(4) Strengthening gauging and stabilizing effects

Besides the gauge protection by cones and tungsten carbide cutters on bit legs, integral gauging metal blocks were set onto the bit body and were arranged in crisscross with three cone legs, with the outer diameter of 309 mm. Columnar gauging tungsten carbide cutters were set by fully tight and cold- setting method on the surface of bit body (Figs. 7.1, 7.3 and 7.4). Practical applications proved that the gauge added onto the bit body played an important role for preventing hole diameter undersize and also effectively reduced hole deviation tendency. However, once a long footage completed by the drill bit and the rock formation was very high in abrasiveness, bit gauge still wore quite seriously.

Fig. 7.4 KZ series pilot reaming bit with rock bit

(5) Design of drill bit fluid passage

A four passageway design was adopted, with the drilling fluid equally distributed for each cone, to fully satisfy the demands of cooling cones and cleaning the hole bottom; the pilot part of the drill bit was also distributed with partial drilling fluid thus a certain uplift drilling fluid velocity was produced in the annulus between the bit pilot body and pilot hole wall, this could prevent the rock debris produced in reaming drilling from settling to the pilot hole bottom, and at the same time, prevent the broken cuttings and rock blocks from aggregating in the lower end of the pilot body, which could be easily worn off.

Nozzle structure was added in the first drill bit KZ01. But drilling practice showed that the addition of the nozzle could lead to an overpressure of the pump. Drilling in hard and brittle rock formations, the function of hydraulic rock fragmentation was not obvious, without evident role of increasing drilling speed. In the meantime, considering no bit balling problem existed, too high nozzle pressure drop could easily cause "pricking leakage" and other problems, and so from the KZ 02 bit on, nozzle was canceled, because with nozzle the disadvantage was more than advantage.

2. **The technical parameters and indexes of KZ157/311.1 reaming bit**

The technical parameters and indexes of KZ157/311.1 reaming bit can be found in Table 7.1.

3. **Process control of KZ157/311.1 reaming bit manufacture**

The decisive factor affecting the service life of rock bit is bearing seal, so during the process of the KZ type rock bit manufacture, besides choosing high quality tri-cone rock bit, the temperature in the process of manufacture must be strictly controlled. In the process of disassembling the tri-cone rock bit, a special technology was adopted, and the welding temperature was strictly controlled in the welding process to prevent the bearing rubber seal and lubricating oil storage capsule from high temperature damage.

Table 7.1 The technical parameters and indexes of KZ157/311.1 reaming bit

Item	Parameter
Bit outer diameter	311.1 mm
Bit pilot diameter	The cone was 152.4 mm, bit steel blank was 156 mm
Bit pilot length	350 mm (later changed to 250 mm)
Bit service life	Under normal drilling conditions, the service life of bit bearing was no less than 60 h, with the maximum over 70 h
Drilling speed	Based upon different rock formations, drilling speed would reach 0.5–1.5 m/h
Bit mass	170 kg

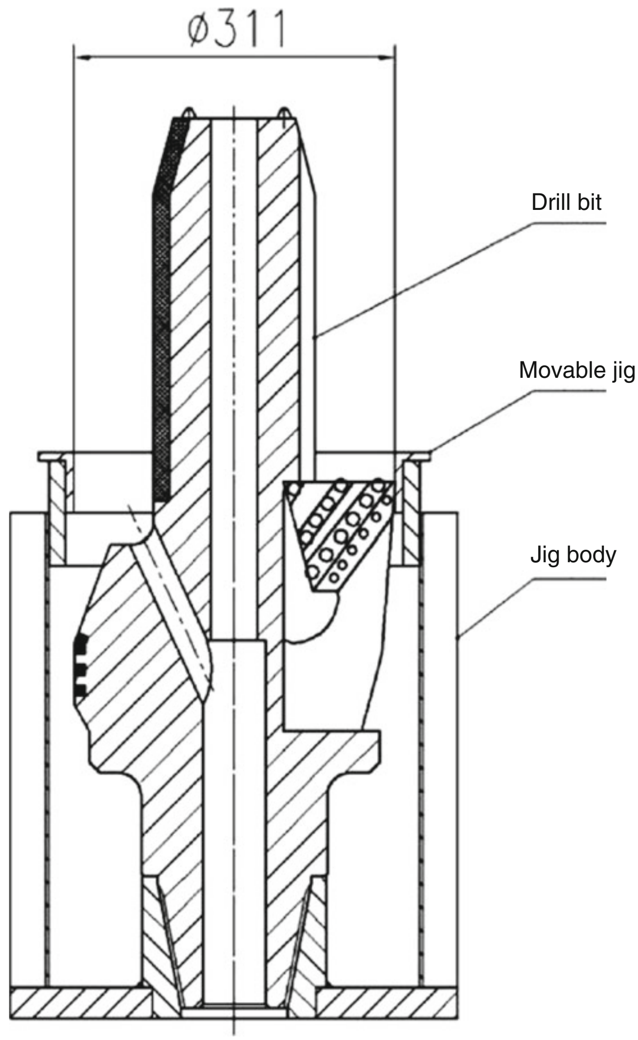

Fig. 7.5 Jig for reaming bit welding

The machining precision of rock bit is also an extremely important factor that affects the application of the rock bit. In order to guarantee the machining precision, all the bit parts were machined before assembling the bit. In addition, a special jig for bit production (Fig. 7.5) was designed to guarantee the concentricity between the thread and the cone pilot body of the bit and guarantee the normality of the bit diameter; the welding technology was strictly controlled in the process of welding to avoid an over deformation which would cause abandonment before use.

7.1.2 KHAT 157/311.1 Reaming Bit

With the basic structure and cone selection the same as KZ series bit, KHAT 157/311.1 reaming bit (Fig. 7.2) also has its own following features:

1. The length of the pilot section was short, the spherical tungsten carbide teeth were used for gauge protection in the outer cylinder surface. There was no cutting tooth at the end surface;
2. The cone legs were designed and manufactured by the original drill bit plant and thus cutting, separation and other procedures were unnecessary. The cone legs could be used directly for welding into the reaming bit;
3. Rich experiences in rock bit assembling and welding techniques were accumulated, the selection of materials and process was correct and thus the welding seams didn't break off.

7.1.3 Development and Improvement of KZ157/244.5 Reaming Bit

KZ157/244.5 reaming bit was manufactured on the base of successful application of KZ157/311.1 reaming bit and keeping design conception and structural advantages of KZ157/311.1 reaming bit. Since the structure space was more narrow, the drilling depth was more deeper and the factors of unstable hole wall increased, the successful development of KZ157/244.5 reaming bit (Fig. 7.6 left) was resulted from the careful design. At the initial stage, following attempts were made for the selection of the cones and the ways of gauging.

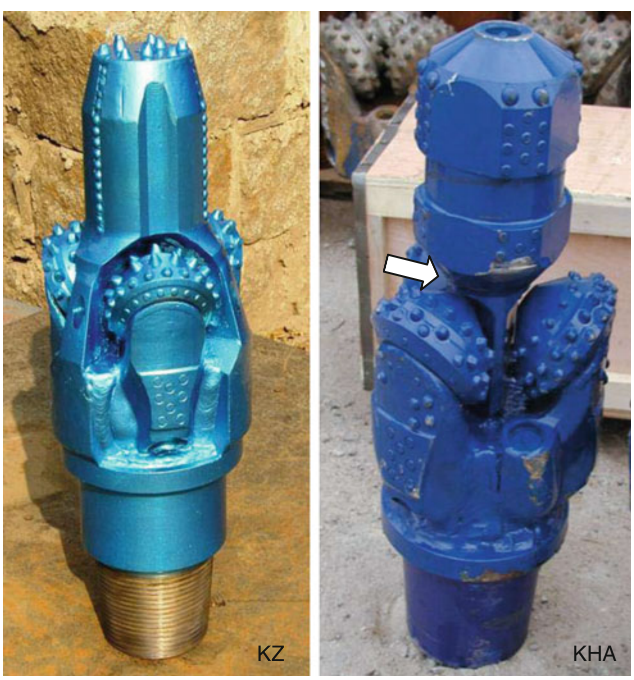

Fig. 7.6 157/244.5 reaming rock bits

1. **Retrofit of cone leg**

Since the structure space of KZ157/244.5 bit body was small, in order to guarantee the structural strength, the cone legs of φ 165.1 mm rock bit were used for the first six rock bits. However, since the cones were small, with small and less tungsten carbide teeth to break rock, and in the meantime, the linear velocity of the bearings was higher, the bit service life was unsatisfactory, as the average actual drilling time was only 16.87 h, the average footage drilled was 14.69 m, and the average penetration rate was 0.87 m/h. Because the gauging teeth were less, the cone diameter wore quickly; basically, the tungsten carbide teeth wore flat in each drilling roundtrip (Fig. 7.7). Penetration rate was lower, drilling speed was lower, and application cost of the bit was fairly high.

After repeated study, starting from the seventh bit, the cone legs of HJ series 215.9 mm (8½ in.) rock bit with metal seal were used. Since the diameter of reaming bit was small, the use of large bit cone legs made the bit body structural strength very weak, especially the strength of juncture area between bit body and pilot body (shadow area of Fig. 7.8), the front pilot body more easily broke off under large twisting. So retrofit of cone leg greatly increased the difficulty in design and manufacture (Fig. 7.8).

In order to solve the problem of bit strength, firstly, the pilot body length and the pilot diameter were appropriately decreased so as to reduce the force borne; secondly, the modification to the cone structure was carried out. Under the precondition that bit application would not be affected, the front point tip of the cone which doesn't break rock was cut off with the air-blasting or electrical cutting so that the front size of the cone was reduced to prevent the interference of the bit body positions from each other and to provide a larger space for increasing the bit body strength; thirdly, while considering the space of the cone positions, the cone body was precisely manufactured by reference to the cone

Fig. 7.7 The $6^1/_2$ in cones of the reaming bit were worn flat

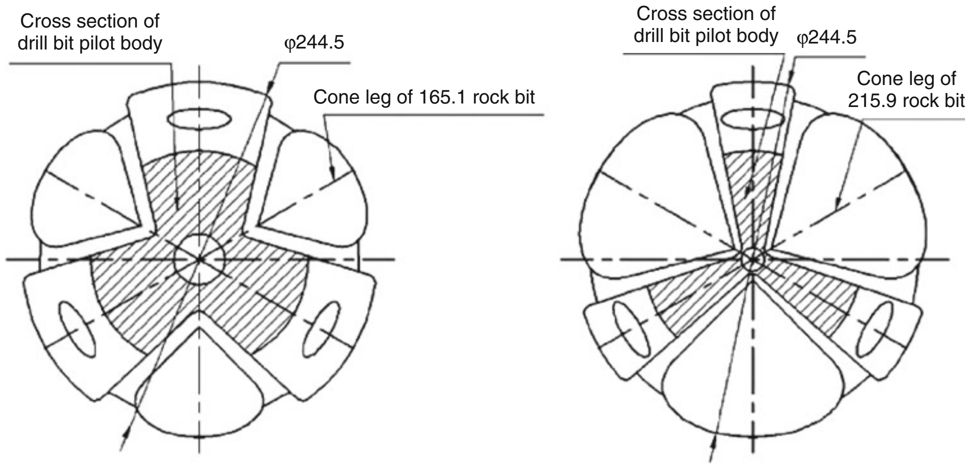

Fig. 7.8 Structure comparison of KZ157/244.5 reaming rock bit with different cone legs

Table 7.2 Comparison of effects on cone leg improvement of KT157/244.5 reaming bit

Statistics range	Bit quantity/piece	Average footage drilled (m/bit)	Average actual drilling time (h/bit)	Average penetration rate (m/h)	Remarks
Before KT157/244.5-6#	6	14.69	16.87	0.87	7 roundtrips
After KT157/244.5-7#	15	64.75	57.89	1.12	17 roundtrips
Contrast of the improvement (after improvement/before improvement)		4.41	3.43	1.29	

shape and the outside space of the cone was fully used to increase the cross-section area for jointing and reserve the solid body parts of the bit as much as possible in order to enhance the structural strength of the bit body.

Application practice proved that the improvement of the rock bit leg obtained a good result, the integral strength of the bit was guaranteed, with the service life of the bit greatly increased (the average drilling time was 57.89 h, the average footage drilled was 64.75 m), the drilling speed increased obviously (Table 7.2). However, when serious sticking or bit bouncing happened with the front pilot body at hole bottom, the pilot body still easily deformed. In MH-1K-27 roundtrip the pilot body of KZ157/244.5-22 bit broke off (Fig. 7.9).

2. **Improvement of gauging methods**

On the base of the successful application of the reaming bit in the first phase, KZ157/244.5 reaming rock bit was also strengthened in gauging. Firstly, the quantity of the inserted tungsten carbide for gauging was increased; secondly, the whole cone legs were inserted with tungsten carbide under the condition that cone leg strength would not be affected. The wear to the bit was improved somewhat, but the gauging ability of the bit did not match the ability of down hole rock fragmentation, undersize of the hole was still serious. Under these circumstances, diamond reamer was used in the drilling tool assembly.

The polycrystalline diamond inserts were attempted for guaranteeing the bit diameter; the polycrystalline inserts,

Fig. 7.9 Falling-off of the pilot body of KZ157/244.5-22 bit

made by the Beijing Institute of Exploration Engineering, were inserted with silver welding onto the gauging section of the bit body. But in practice, the polycrystalline diamond insert was not as good as the tungsten carbide in gauge protection. The reasons included that the hardness and strength of the polycrystalline diamond inserts were lower and the

Fig. 7.10 Wearing on gauge of the reaming bit

working area for gauge protection was small, in the process of cutting rock in lower rotation and larger torque, the cutters cut the rock with powerful squeezing-pressing and percussive actions, the diamond inserts could not bear such a large impacting force and then deformed and partially fell off, with diamond grains falling off together with the matrix, so that polycrystalline diamond insert could not act for gauge protection (Fig. 7.10).

7.2 Design of Drilling Tool

7.2.1 Strength Check of Drilling String

1. **The calculation equations of the drill string strength**
1. WOB
   Refer to the section of optimization of drilling parameters in this chapter.
2. The total length of the drill collars

$$\textit{the needed collar weight} = \frac{\textit{designed maximum WOB} \times \textit{saftey factor}}{\textit{buoyancy factor of drilling fluid}} \tag{7.1}$$

$$\textit{the total length of collar} = \frac{\textit{the needed collar weight}}{\textit{collar weight per meter}} \tag{7.2}$$

3. The total length of drill rods

$$\textit{the total length of drill rods} = \textit{hole depth} - \textit{the total length of collar} \tag{7.3}$$

4. Tensile stress of the upper drill string
   While the drill string is hanged up, the tensile stress of the drill rods in drilling fluid is:

$$\sigma_{L1} = \frac{QK}{A} \tag{7.4}$$

in which

σ_{L1} tensile stress of the drill rods hanged up in drilling fluid, MPa
Q the weight of the drill rods in air beneath the hole mouth, N
K the buoyancy factor
A cross section of the drill rod at hole mouth, mm^2

In drilling, the tensile stress:

$$\sigma_{L2} = \frac{QK - P}{A} \tag{7.5}$$

where

Q the weight of the whole drill string in air, N
P WOB, N

During tripping, the tensile stress is:

$$\sigma_{L3} = 1.5 \times \frac{QK}{A} \tag{7.6}$$

5. Compressive stress of the lower drill string

$$\sigma_Y = \frac{P}{A} \tag{7.7}$$

in which

σ_Y the compressive stress of the lower drill string, MPa
P WOB, N
A calculated cross section area, mm^2

6. Shear stress

$$\tau = \frac{9.8 \times 10^6 \cdot N \cdot k \cdot \eta}{n \cdot W} \tag{7.8}$$

where

τ the shear stress, MPa
N the power of power engine, kW
k the possible overload factor of power engine
η transmission efficiency form power engine to rotary table

n rotary speed of drill string, r/min
W the modulus of torsional resistance cross-section of the checked drill string, mm^3

7. Bending stress

$$\sigma_W = \frac{100 \cdot M}{W} \tag{7.9}$$

in which

σ_W bending stress, MPa
M the maximum bending moment, N·m
W the modulus of the bending resistance cross section of the drill string, mm^3

8. the compound stress in drilling

The compound stress of the upper drill string:

$$\sigma_1 = \sqrt{(\sigma_{L2} + \sigma_W)^2 + 4\tau^2} \tag{7.10}$$

where

σ compound stress of the upper drill string, MPa
σ_{L2} tensile stress of the upper drill string, MPa
σ_W bending stress, MPa
τ shear stress, MPa

The compound stress of the lower drill string:

$$\sigma_2 = \sqrt{(\sigma_Y + \sigma_W)^2 + 4\tau^2} \tag{7.11}$$

in which

σ compound stress of the lower drill string, MPa
σ_{L2} compressive stress of the lower drill string, MPa
σ_W bending stress, MPa
τ shear stress, MPa

2. **Check of drill string strength**

With help of the above-mentioned strength check methods of the drilling tools used in oil drilling, substituting the input power and transmission efficiency of the rotary table, WOB, rpm, total drilling tool weight, cross-section area of the drill rods, parameters of drill rod mechanical performances, drilling fluid density and other basic parameters of ZJ70D drill into the formulas, the drilling tool strength was checked, with the result that the φ 127 mm oil drill rod of G105 steel grade, which met the strength demands in the drilling, was suitable to 3800 m hole depth. However, considering the larger vibration of the drilling tool and more frequent stress alteration in reaming drilling, the drill rod of higher grade steel was still more suitable for reaming drilling. Therefore it was decided that S135 grade steel should be used for the drill rod for reaming drilling, with data shown in Table 7.3.

7.2.2 Selection of Drilling Tools

In reaming drilling, in order to increase the stability of the drilling tool in the hole, appropriate numbers of stabilizers were added to the drilling tool assembly. Considering the frequent and serious drilling tool bouncing, shock absorber was added to the downhole drilling tool assembly. In order to deal with the possible sticking accident, jar-while-drilling was added to the drilling tool assembly so that the sticking of the drilling tool could be released. After serious wear of the bit gauge protection occurred, diamond reamer was added above the drill bit.

1. **Impregnated diamond reaming shell**

Because of the strong abrasiveness of the rock formations, the gauge protection ability of the reaming rock bits was not enough, during reaming drilling, the bit gauge protection wore quickly with the outer diameter of the drill bit and the hole size undersized. The new drill bit could not be run into the hole bottom in the next roundtrip and redressing would be conducted.

The above case, especially after three HAKT reaming rock bits were continuously used in φ 311.1 mm reaming hole section, became more serious. The follow-up new bits wore off at outside diameter when reaching to the hole bottom. To solve this, it was decided that an impregnated diamond reamer would be added on the reaming rock bit. The diamond reamer was made by the sintering processing with hot pressing and twice forming, and impregnated diamond matrix was used as the cutting element.

In φ 311.1 mm reaming-hole, it was not until the MH-1K-42 Roundtrip that the diamond reamer was used. At first, a long steel bar brazed with impregnated diamond matrixes was welded onto the drilling tool, so as to decrease the cost. In the late phase, considering the quality problems of the welding, the integral diamond reamers were made. The two ends of the diamond reamer wings were conical shape, with diamond matrixes welded at the conical section. The diamond matrix was made of natural diamond and SDA100 + synthetic diamond. The diamond layer thickness in gauge protection was 3.5 mm, and in the lower conical section was 5 mm, with the diamond concentration of 100 % and the matrix hardness of HRC40 ± 3. The size of the impregnated diamond matrix was 30 mm × 10 mm × 10 mm. For each reamer, there were 8 reaming strips, on each of which there were 21 impregnated diamond matrixes, with the total of 168 matrixes. The length of the diamond reaming strip was 200 mm (Fig. 7.11a).

In φ 244.5 mm reaming drilling, the integral structure reamer was used. Differing from φ 311.1 mm reaming drilling, a lot of polycrystalline diamonds were inserted into the impregnated diamond matrixes and the gauge protection ability of the diamond reamers was further increased. Six diamond reamers were totally used in this phase (Fig. 7.11b).

Table 7.3 Data for checking drilling tool strength in reaming drilling

Reaming size and hole section			φ 157/311.1 (101.00–2033.00 m)			φ 157/244.5 (2028.00–3625.18 m)		
Drilling tool			Drill rod	Collar	Collar	Drill rod	Collar	Collar
Size/mm			127	177.8	203.2	127	177.8	203.2
Steel grade			S135			S135		
Inner diameters (mm)			108.6	71.4	71.4	108.6	71.4	71.4
Unit weight (N/m)			284.7	1606	2190	284.7	1606	2190
Length (m)			1888	27	54	3500	54	27
Weight per section (kN)			538	43.5	118	997	87	59
WOB (kN)			100			58		
Rpm (r/min)			85			70		
Mud density (g/cm^3)			1.06			1.06		
Tensile force margin (kN)			2420			2006		
Tensile strength (kN)			3107			3107		
Torsion yield (kN•m)			100			100		
Safety factor	Tension	Design requirement	1.8			1.8		
		Actuality	3.65			2.72		
	Torsion	Design requirement	1.25			1.25		
		Actuality	17			17		

After using the diamond reamers, the situation of hole undersize was obviously improved, and the redressing time was reduced during running-in the drilling tool.

2. **Double direction shock absorber**

Since the formations drilled were very hard and the rock in some hole sections was broken, in reaming-drilling, the annular area of reaming was bigger and thus the vibration of drilling tool was unavoidable, and sometimes it could affect the reaming drilling effect, especially in the hole sections with severe deviation change. The shock absorber could effectively absorb various vibrations caused in drilling and improve bouncing of the drilling tool, thus the normal reaming drilling could be effectively guaranteed. The double direction shock absorber is a kind of drilling tool which can alleviate or eliminate the vertical and peripheral vibrations of the drill string, to keep normal WOB and torque so as to reduce the vibration damages to drilling tools and equipment while to increase drilling speed and decrease drilling cost. After the double-direction shock absorber was used in reaming drilling, bit bouncing was obviously improved, and the down hole accidents were evidently reduced. Large WOB could be exerted to the drill bit during drilling and thus the drilling speed was increased.

3. **Stabilizer**

The purpose to set stabilizer (Fig. 7.12) was to centralize drill collar and stabilize drilling tool, and to reduce the wear of drilling tool. Meantime, when inflection point occurred in the hole, the stabilizer could rectify the hole wall to some extent.

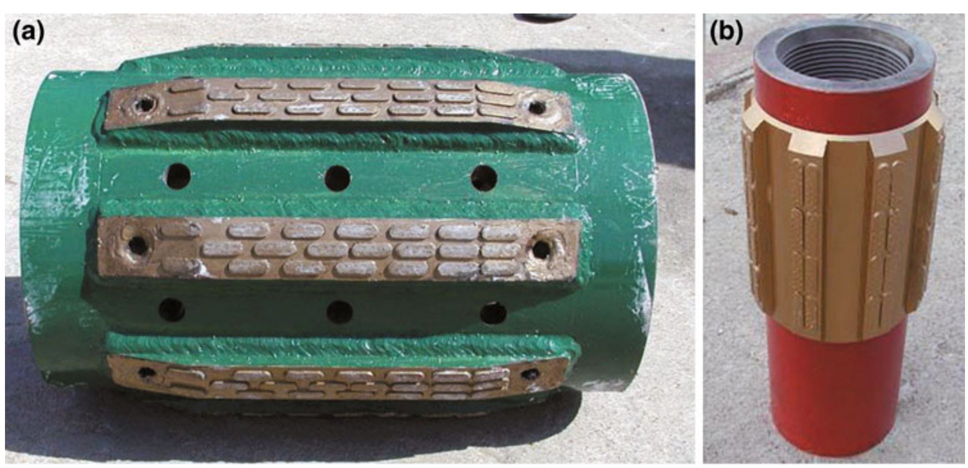

Fig. 7.11 Diamond reaming shells for reaming drilling. **a** φ 311.1 mm diamond reamer, **b** φ 244.5 mm diamond reamer

Fig. 7.12 Stabilizer used in reaming drilling

The main factors that should be considered for setting the stabilizer included outer diameter, length, number and setting position of the stabilizer. Usually, two stabilizers were set in the drilling tool assembly, under the collar. The two stabilizers were set at a distance of one or two pieces of drill collar.

The outer diameters of the stabilizers used in φ 311.1 mm reaming drilling were φ 309 and φ 305 mm. Since the outer diameter of the reaming bits was not standard, especially for the reaming bits in preliminary phase, the outer diameter was less than φ 311.1 mm in most cases, being only φ 309 mm, and the outer diameter of a few reaming bits was even φ 308 mm, after using φ 309 mm stabilizer, it was easy to cause bit bouncing and even cause rough drilling. Therefore, when reaming drilling was conducted in MH-1K-17 roundtrip, φ 305 mm stabilizer was used instead of φ 309 mm stabilizer, and by adjusting the position of the stabilizer, reaming drilling was more stable.

The outer diameter of the stabilizers used in φ 244.5 mm reaming drilling was φ 214 mm.

4. **Double direction jar while drilling**

The jar-while-drilling was used to release the vibration force (upward or downward) and free the sticking when the drilling tool was stuck in the hole. During the second reaming drilling, the hole condition was complicated, with falling fish and falling rocks caused by formation collapse. Thus it was necessary to set the jar onto the drilling tool. According to practical conditions and drilling tool assembly used in this hole section, drilling tool sticking point was mainly at the drill bit, therefore, the jar-while-drilling was set at the lower end of the collar and the upper end of shock absorber. In the operations of releasing drilling tool sticking, the jar-while-drilling played a very important role.

5. **Hydro-hammer**

The development of hydro-hammer was one of the pre-research projects of CCSD, during the period of φ 311.1 mm reaming drilling, hydro-hammer originally designed for non-core drilling was run in hole for testing eight roundtrips in all. KSC-203 hydro-hammer was run in hole for testing three roundtrips in all, and SYZX-273 hydro-hammer (Fig. 7.13) was run in hole for testing five roundtrips with the longest continuous working time of only 17 h. Hydro-hammer obviously increased drilling speed. Since the testing of the hydro-hammers was arranged in the middle of the production drilling, there was no enough time to solve the problems found in the testing, so, in the whole process of reaming drilling, hydro-hammer didn't play a proper role.

The influence of the percussive power of hydro-hammer to drilling effect and rock bit was obvious. For instance, when SYZX-273 hydro-hammer was run in the MH-1K-47 roundtrip for testing, the bit used was φ 311.1 mm ($12^1/_4$ in) rock bit, and the rock in this hole section was amphibolite and eclogite. The hydro-hammer only worked for 4 h, with the footage drilled of 53 m in this roundtrip. The teeth of the bit cone broke and seriously wore, the bearings of three cones all loosened and lost efficacy (Fig. 7.14). The matching between the parameters of the hydro-hammer and

Fig. 7.13 SYZX-273 hydro-hammer and the affiliated 311 mm button bit

Fig. 7.14 Rock bit lost efficacy

the working properties of the rock bits still needed further study, otherwise, the service life of the bit would be affected.

7.2.3 Design of Drilling Tool Assembly

1. **φ 157/311.1 mm reaming drilling tool assembly**

According to the principle of drill collar grading and the result of drill string strength checking, φ 157/311.1 mm reaming drilling tool assembly can be found in Table 7.4, and the schematic drawing of the drilling tool assembly in Fig. 7.15.

Pilot reaming drilling tool assembly was mainly used for conventional reaming drilling, being a main drilling tool assembly form in reaming drilling. Pilot reaming drilling tool without stabilizer was mainly used in the period that drilling tool rotation torque needed to be reduced, by using this drilling tool the rotation resistance could be reduced, and meantime rock block dropping and drilling tool sticking could be avoided. This drilling tool was mainly used in the late phase of reaming drilling. Reaming drilling tool assembly with reamer was mainly used for rectifying the hole wall and drilling-off for setting casing in the final reaming drilling phase.

The starting phase of reaming drilling was mainly for exploring the drilling bit structure and drilling technology, so the footage drilled per roundtrip was short. Reaming drilling went into normal after solving the problems of welding seam strength of the drill bits. Since the long delivery term of vibration absorber, the vibration absorber was not used to the drilling tool assembly until the MH-1K-17 roundtrip; the vibration absorber alleviated the bouncing of the drilling tool to a certain extent. After that, the drilling tool assembly was adjusted mainly according to the hole bottom conditions, which are described as follows.

The stabilizer was disassembled from the drilling tool assembly from the MH-1K-27 roundtrip, the torque of the drill bit, which was caused due to the dog-leg degree, was decreased in borehole so that the drilling tool accident would be averted in deep hole section. Diamond reamer was jointed on the drill bit for reaming from the MH-1K-42 roundtrip, at the same time of drilling, previous hole wall was rectified and the drilling-off workload was reduced to the follow-up new bit and the hole undersize phenomenon was improved.

From the MH-1K-44 roundtrip, considering the obvious variation of the hole vertex angle at the hole bottom in this section and large resistance to the big rigidity reaming drilling tool in drilling operation, flexible pendulum drilling

Table 7.4 φ 157/311.1 reaming drilling tool assemblies

Drilling tool	Drilling tool assembly
Conventional pilot reaming drilling tool	φ 157/311.1 mm reaming bit + vibration absorber + φ 203.2 mm collars × 18 m + φ 309 mm stabilizer + φ 203.2 mm collar × 9 m + φ 309 mm stabilizer + φ 203.2 mm collar × 27 m + φ 177.8 mm collar × 27 m + φ 127 mm drill rod
Hydro-hammer drilling tool assembly	φ 157/311.1 mm reaming bit + φ 273 mm or φ 203 mm hydro-hammer × 3.2 m + vibration absorber + φ 203.2 mm collar × 9 m + φ 309 mm stabilizer + φ 203.2 mm collar × 8 m + φ 309 mm stabilizer + φ 203.2 mm collar × 27 m + φ 177.8 mm collar × 27 m + φ 127 mm drill rod
Pilot reaming drilling tool assembly without stabilizer	φ 157/311.1 mm reaming bit + vibration absorber + φ 203.2 mm collar × 54 m + φ 177.8 mm collar × 27 m + φ 127 mm drill rod
Reaming drilling tool assembly with reamer, without pilot	φ 311.1 mm tri-cone rock bit + diamond reamer + φ 203.2 mm collar × 9 m + φ 309 mm stabilizer + φ 203.2 mm collar × 9 m + φ 309 mm stabilizer + φ 203.2 mm collar × 36 m + φ 177.8 mm collar × 36 m + φ 127 mm drill rod

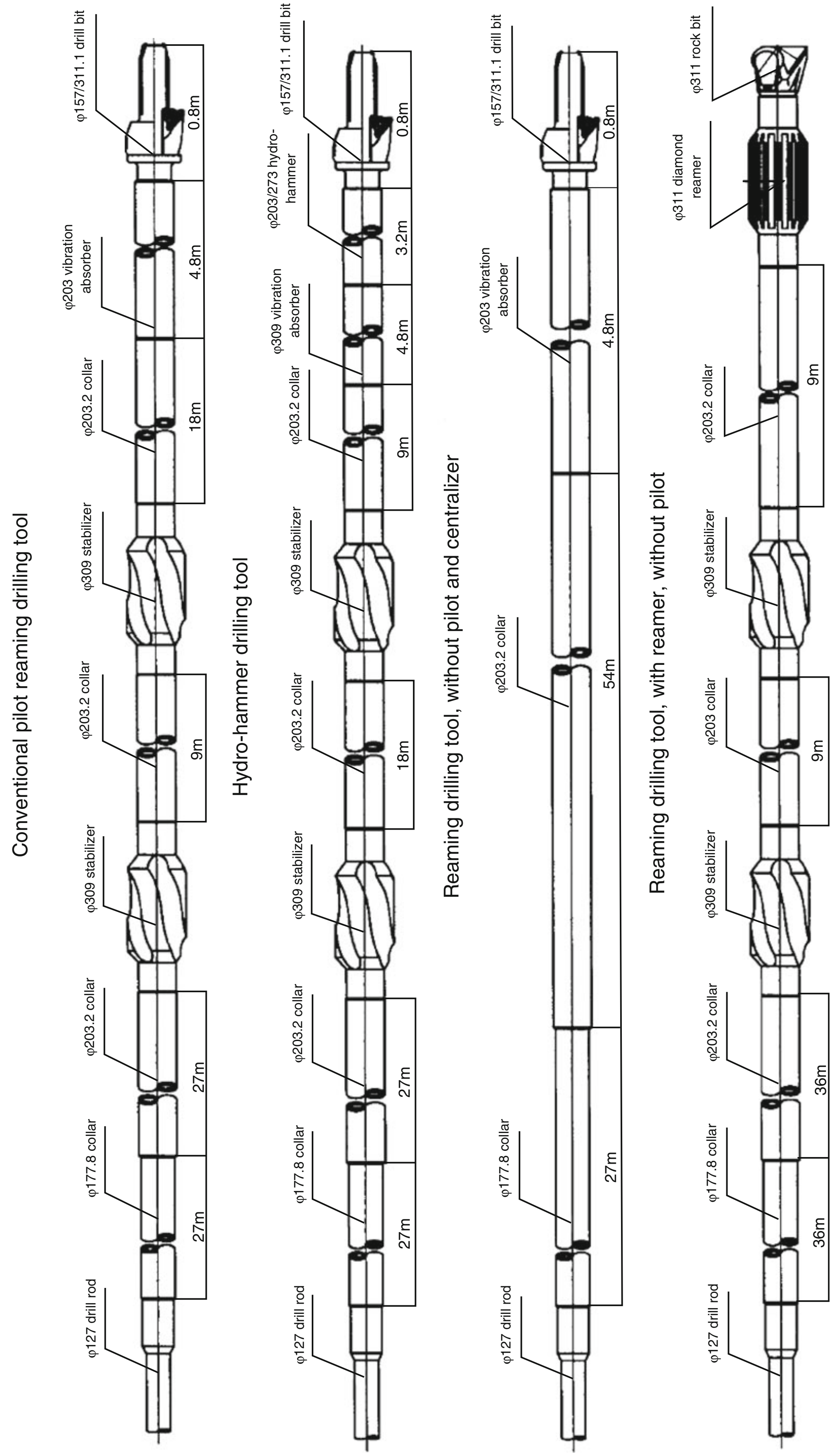

Fig. 7.15 157/311.1 reaming drilling assemblies

tool (φ 203.3 mm collar between two stabilizers was changed to φ 158.8 mm collar) and non-core tri-cone rock bit were used and the gauge protection diamond reamer was disassembled, the pilot capacity of the drilling tool was decreased in hope that the follow-up drilling would not be affected by original hole trace, the hole dog-leg degree and vertex angle would be decreased in order to lay a solid foundation for the follow-up drilling (however, since the pilot hole had already formed a slim hole as a free fragmentation face, it was impossible to completely separate from the slime hole, but it would be possible to partially alleviate the hole deflection intensity). In the MH-1K-47 roundtrip, after the redressing was carried out again for rectifying the hole wall, cementing bag was drilled, then the reaming drilling was accomplished in this hole section.

2. **φ 157/244.5 mm reaming drilling tool assembly**

In φ 157/311.1 mm reaming, diamond reamer was designed in order to rectify the hole size. The drilling tool assembly for φ 157/244.5 mm reaming (Table 7.5) was basically the same as that for φ 157/311.1 mm reaming, with the schematic drawing in Fig. 7.16.

Based upon the experiences that using tri-cone rock bit didn't deviate off the axis of the original slim hole in φ 157/311.1 mm reaming drilling, and considering that pilot reaming drill bit had large torque, pilot body was easily to stick, and the whole body strength was less than the conventional tri-cone rock bit under complicated down hole condition and large torque condition, tri-cone rock bit reaming drilling tool assembly was mainly used in reaming drilling. The flexible tri-cone rock bit reaming drilling tool assembly was sometimes used in order to avoid sticking and breaking of the pilot body of the pilot reaming drill bit, when the down-hole condition was relatively complicated and the spring leaf of the elastic stabilizer of the moving casing might fall off.

In reaming drilling of this phase, there were a lot of broken spring leaves and broken pilot body of the drill bit at the hole bottom, a slim hole milling tool assembly was used to mill the falling objects and to drill off the slim hole for many times in order to prevent the damage to the drill bits and hole accidents. In the drilling process after 3447 m, there were not only "falling fish" and debris, but also the falling rock blocks from the hole wall resulted from hole oversize, and then milling shoe and fishing-debris drilling tool assemblies were used to fish and mill the debris at the hole bottom, shown in Table 7.6 and Fig. 7.17.

7.3 Optimization of Drilling Parameters

7.3.1 WOB

WOB for reaming rock bit should be less than that for conventional tri-cone rock bit with same size.

The load bearing condition of reaming bit was inferior to that of integral tri-cone rock bit, the pilot body bore very large bending torque, the vibration was large while drilling, and bouncing easily happened to produce large damage force to the cone leg welding seam. In addition, the cone body of the reaming rock bit was smaller; excessive WOB could cause an early damage to the cone bearings.

According to the foreign experiences and on-the-spot experimental research, the specific pressure of reaming drilling was 0.25–0.65 kN/mm (hole diameter-pilot hole diameter). WOB for φ 157/311.1 mm reaming drilling was 38.5–100 kN, and WOB for φ 157/244.5 mm reaming drilling was 22–57 kN.

The practical WOB should be adjusted according to the conditions of the formations to be drilled. If bit bouncing occurred in drilling, small WOB should be taken for further drilling. Low WOB was to be used in the initial phase of each roundtrip, after the wear of tungsten carbide teeth, WOB was gradually increased to ensure drill bit to cut the rock effectively.

7.3.2 Rotary Speed

The rotary speed of drill bit mainly depends on the time used for bit teeth breaking the rock, the formation strength drilled and the bearing capacity of the bearings. According to the

Table 7.5 φ 157/244.5 mm reaming drilling tool assemblies

Drilling tool	Drilling tool assembly
Conventional pilot reaming drilling tool	φ 157/244.5 mm reaming bit + φ 244 mm diamond reamer + φ 203 mm vibration absorber + φ 203.2 mm collar × 27 m + φ 178 mm vibration absorber + φ 214 mm stabilizer + φ 177.8 mm collar × 54 m + φ 127 mm drill rod
Flexible pilot reaming drilling tool	φ 157/244.5 mm reaming bit + φ 244 mm diamond reamer + φ 203 mm vibration absorber + φ 178 mm vibration absorber + φ 214 mm stabilizer + φ 177.8 mm collar × 72 m + φ 127 mm drill rod
Flexible tri-cone rock bit reaming drilling tool	φ 244.5 mm tri-cone bit + φ 244 mm diamond reamer + φ 203 mm vibration absorber + φ 178 mm vibration absorber + φ 214 mm stabilizer + φ 177.8 mm collar × 90 m + φ 127 mm drill rod

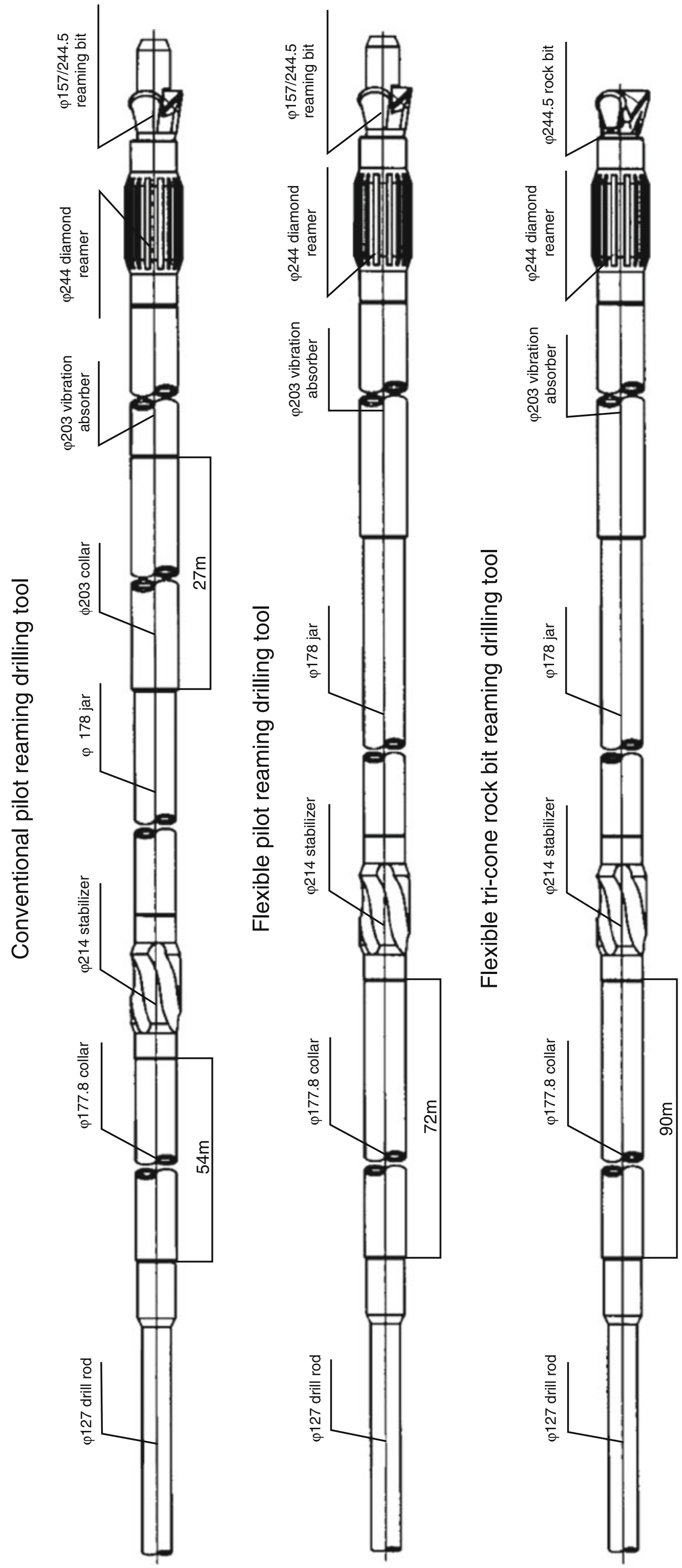

Fig. 7.16 157/244.5 reaming drilling assemblies

Table 7.6 φ 157/244.5 mm drilling tool assemblies for milling, drifting and fishing debris

Drilling tool	Drilling tool assembly
Slim hole drilling tool assembly for milling hole	φ 150 mm milling shoe + SK153 stabilizer + SK146 wire-line coring collars × 54 m + SK139.7 wire-line drill rod × 27 m + φ 178 mm jar + φ 214 mm stabilizer + φ 177.8 mm collar × 54 m + v 127 mm drill rod
Milling shoe + fishing-debris drilling tool assembly	φ 158.8 mm rock bit + φ 89 mm drill rod + φ 193.7 mm × 4.38 m special 1# fishing cup + φ 193.7 mm × 6.52 m special 2# fishing cup + φ 203 mm vibration absorber + φ 178 mm jar + φ 214 mm stabilizer + φ 177.8 mm collar × 90 m + φ 127 mm drill rod

research on rock fragmentation by tungsten carbide teeth from Biryukov, a scholar of the former Soviet Union, the contact time (t) between the rock and teeth is no less than 0.02–0.03 s, if less than 0.02–0.03 s, the acting effect that teeth exert the pressing force onto the rock will decrease sharply. According to above theory, the rotary speed range of φ 311.1 mm reaming rock bit could be obtained.

Suppose the big end diameter of the cone is d, the teeth number of the big end is z, the bit diameter is D, than an arc length between the teeth of the big end of the cone L = πd/z, the linear velocity of rotation of big end of the cone V_G = L/t, and then V_G = πd/zt. Under pure rolling, n/n_G = d/D, and then n_G = nD/d, in which, n is bit rotary speed, n_G is the rotary speed of the cone.

Considering that the teeth of reaming rock bit do not roll purely at hole bottom, the rotation speed decreases slightly, therefore, the above formula should be corrected to n_G = knD/d, in which, k = 0.95 is the thumb experience factor of the velocity loss.

From $V_G = \frac{\pi d n_G}{60}$, $n_G = \frac{60V_G}{\pi d} = \frac{60\pi d}{\pi d z t} = \frac{60}{zt} = k\frac{nD}{d}$

Obtain:

$$n = \frac{60d}{Dkzt} \tag{7.12}$$

For φ 157/311.1 mm rock bit, to put k = 0.95, t = 0.02–0.03 s, z = 19, d = 130 mm, D = 311.1 mm into the formula (7.12), and then we can obtain n = 46.3–69.5 r/min.

For φ 157/244.5 mm rock bit, to put k = 0.95, t = 0.02–0.03 s, z = 19, d = 130 mm, D = 244.5 mm into the formula (7.12), and then we can obtain n = 59–88 r/min.

In addition, while the reaming rock bit drilling in hard formations, in the arrangement design of the cones, big axial and radial slip shift existed, excessive high revolution could lead an early damage, and meantime, the journal bearing structure of the cone could not bear such high revolution. So, the rotary speed of the reaming rock bit should be limited to a reasonable scope of 40–70 r/min.

In the process of drilling, the upper limit of WOB and rotary speed ranges could not be used at the same time, otherwise, the severe bouncing of drilling tool would take place while drilling and it would be easy to cause hole accidents, rotary speed should be adjusted often in the light of the bouncing of the drilling tool at hole bottom. Therefore, rotary speed and WOB used for reaming drilling were lower, the practical rotary speed in drilling was 45–60 r/min.

7.3.3 Pump Displacement

In theory, the larger the pump displacement is, the better the effect of cleaning out the cuttings at hole bottom will be, the minimum uplift flow rate of the mud should be no less than 0.5 m/s:

In φ 311.1 mm reaming drilling, the pump displacement $Q = v\pi(D^2 - d^2)/4 = 0.5 \times 10 \times 3.14 \times (3.111^2 - 1.27^2)/4 = 32L/s$.

According to mud performance and pump conditions at the drill site, the pump displacement range for φ 157/311.1 mm reaming drilling was 30–35 L/s.

The pump displacement in φ 244.5 mm reaming drilling $Q = v\pi(D^2 - d^2)/4 = 0.5 \times 10 \times 3.14 \times (2.445^2 - 1.27^2)/4 = 17L/s$.

According to mud performance and pump conditions at the drill site, the pump displacement range for φ 157/244.5 mm reaming drilling was 25–30 L/s.

7.4 Effect of Reaming Drilling

7.4.1 General Drilling Conditions

The reaming drilling of CCSD-1 Well was mainly divided into two times:

1. **The first reaming drilling of the main hole**

After the pilot hole was finished, since the quality of the hole body was relatively ideal, with the maximum deviation of only 4.1°, which was far less than the 14° deviation of the original design, in accordance with the double-hole design program, a decision was made to directly ream the φ 157 mm pilot hole to φ 311.1 mm (12½ in.). In May of 2005, after φ 157 mm core drilling to 2046.54 m depth in the pilot hole, the upper φ 244.5 mm (9⅝in.) moving casings were pulled out, the hole section from 101.00 to 2033.00 m was reamed to φ 311.1 mm in diameter, and then φ 273.1 mm technical

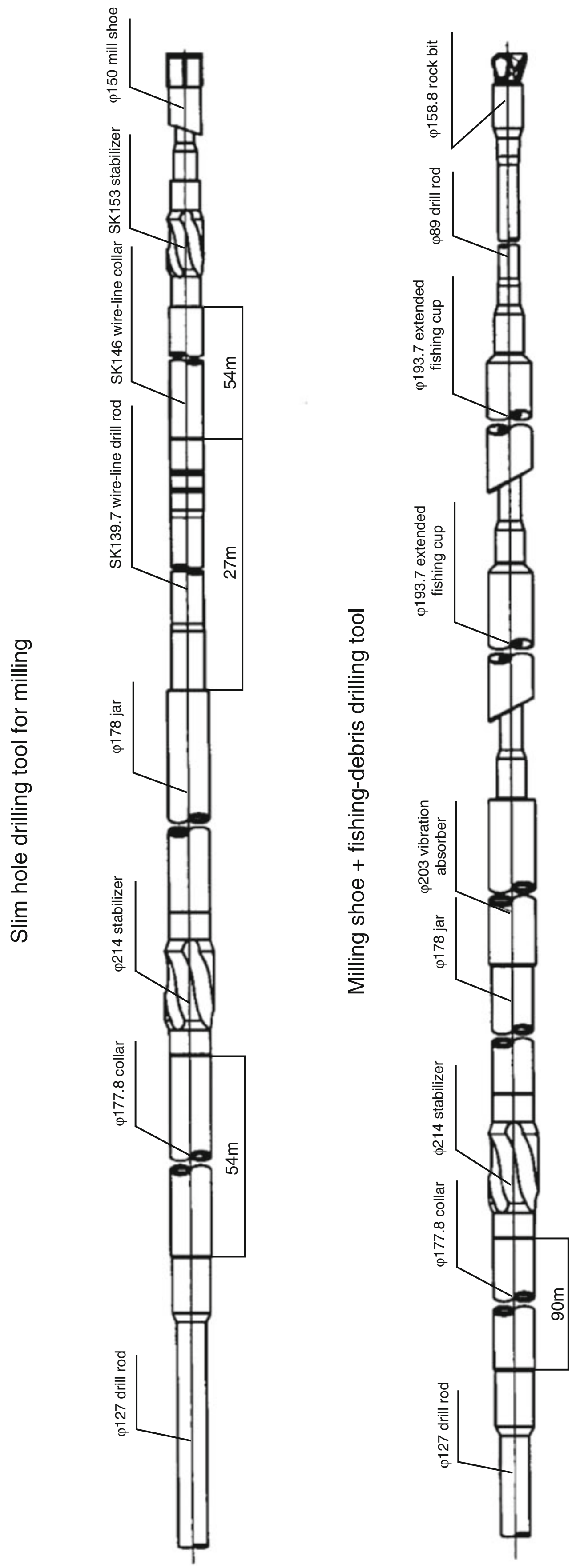

Fig. 7.17 157/245 drilling assemblies for milling, drifting and fishing cuttings

casings and φ 193.7 mm moving casings were set in, afterwards, coring drilling was carried out in the main hole. Reaming drilling lasted 122 days.

2. **The second reaming drilling in the main hole**

In October 2003, when core drilling in the main hole reached to 3665.87 m, the lower reamer of the core drilling tool broke down and lead to an accident in the hole. The fishing operations were carried out repeatedly for many times but without any success. And meantime, in the process of handling the accident, sticking of the drilling tool also occurred because of the falling rock blocks from the upper hole wall, besides, a casing program had been planned in the design in this hole section. For safe drilling and preventing a serious hole accident in follow-up drilling, and meantime, for bypassing the "fallen fish", a decision was made to carry out the second reaming drilling. The upper φ 193.7 mm moving casings were pulled out, the hole section from 2028 to 3525.18 m was reamed to φ 244.5 mm diameter. After sidetracking drilling, φ 193.7 mm technical casings were set in, and then core drilling in the main hole continued. It took 141 days for reaming drilling in this hole section.

The situation of the two reaming drillings can be found in Table 7.7, the technical index of the reaming drilling in Table 7.8, the variations of the service life and the rate of penetration of the reaming bits with hole depth changes for the first and the second reaming drillings respectively in Figs. 7.18 and 7.19.

7.4.2 Application of Pilot Reaming Bits

1. **KZ157/311.1 reaming bit**

From the start of reaming drilling on May 7th, 2002 to the end of the reaming on September 5th, 2002, twenty seven KZ reaming bits were used in succession and satisfactory

Table 7.7 The situations of the reaming drilling

Reaming drilling	Drilling date	Day	Hole section (m)	Diameter of reaming hole (mm)	Reaming bit				
					Piece	Total footage (m)	Footage (m/bit)	Service life (h/bit)	Drilling speed (m/h)
I	2002.05.07–2002.09.05	122	101–2033	311.1	34	1926.89	56.67	54.13	1.05
				215.9	1	5.00	5.00	3.43	1.46
				Subtotal	35	1931.89	55.20	52.68	1.05
II	2003.10.29–2004.03.14	141	2028–3525.18	244.5	28	1497.18	53.47	50.18	1.07
Total		263			63	3429.07	54.43	51.57	1.06

Note Milling drilling for 0.11 m in the first reaming drilling, φ 215.9 mm rock bit was still usable

Table 7.8 The technical statistics of the reaming drilling

Reaming drilling method		Bit/piece	Roundtrip	Total footage (m)	Actual drilling time (h)	Rate of penetration (m/h)	Footage drilled per roundtrip (m)
The first reaming drilling	157/311.1 reaming rock bit	30	42	1770.37	1684.85	1.05	42.15
	311.1 tri-cone rock bit	3	4	156.01	153.79	1.01	39.00
	311.1 flat face bit for hydro-hammer	1	1	0.51	1.67	0.31	0.51
	215.9 tri-cone rock bit	1	1	5.00	3.43	1.46	5.00
	Subtotal	35	48	1931.89	1843.74	1.05	40.25
The second reaming drilling	157/244.5 reaming rock bit	22	25	1145.46	1145.46	1.09	45.82
	244.5 tri-cone rock bit	6	9	351.72	349.34	1.01	39.08
	Subtotal	28	34	1497.18	1404.98	1.07	44.03
Total of two reaming drilling operations		63	82	3429.07	3248.72	1.06	41.82

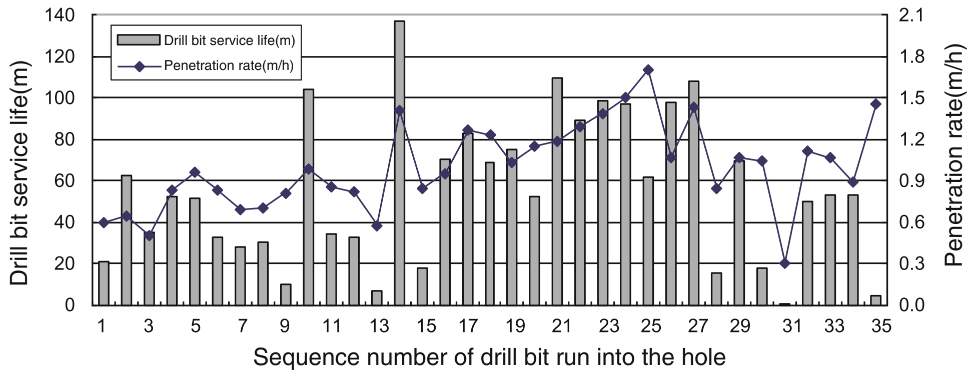

Fig. 7.18 Variation of service life and the rate of penetration of the reaming bits versus hole depth change for the first reaming drilling No. 1–18 and No. 22–30 bits were KZ pilot reaming bits; No. 19–21 bits were KHAT pilot reaming bits; No. 3 bit was spherical teeth full face percussive bit; No. 32–34 bits were φ 311.1 mm tri-cone rock bits; No. 35 bit was φ 215.9 mm tri-cone rock bit

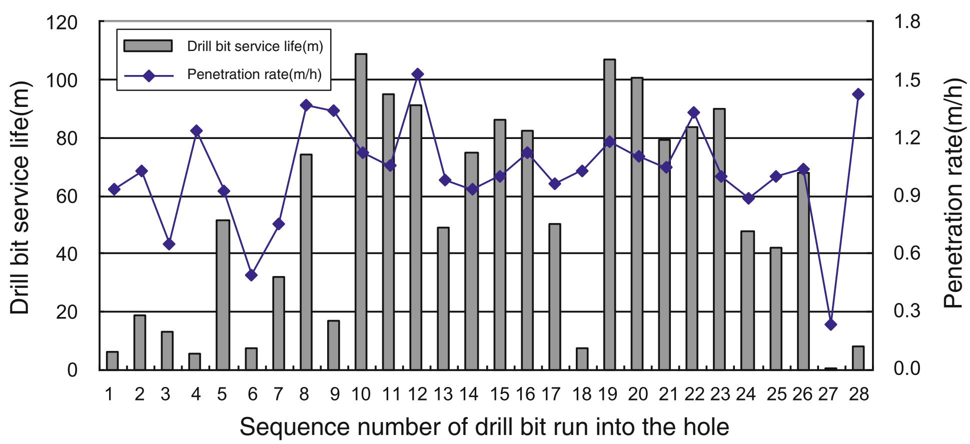

Fig. 7.19 Variation of service life and the rate of penetration of the reaming bits versus hole depth change for the second reaming drilling No. 1–2, No. 4, No. 6–9, No. 12–13, No. 16–27 bits were KZ pilot reaming bits; No. 15 bit was KHAT pilot reaming bit; No. 3, No. 5, No. 10, No. 11, No. 14, No. 28 bits were φ 244.5 mm tri-cone rock bits

results were obtained in the rock formations with drillability of Grade 7–11. The total reaming footage was 1534.05 m, the average rate of penetration was 1.04 m/h, the highest penetration rate was 1.7 m/h. The longest service life of a single bit was 105.94 h, and the highest footage was 136.53 m (Table 7.9).

According to the testing results, it can be found that the bits with vibration absorber had better application effect than those without vibration absorber. In the initial stage of bit application, the bit was not mounted with vibration absorber so that WOB and rotary speed could not be fully exerted to the bit, the drilling tool bounced seriously. After the vibration absorber was added to the bit, drilling became normal, WOB could be increased to 7–9 t, the rotary speed was increased to 50–60 r/min. However, when hydro-hammer was added on the bit, the abnormal damage of the bearings or the tungsten carbide teeth of the bit was serious.

2. **KHAT 157/311.1 reaming bit**

Three KHAT reaming bits were used, with the total reaming footage of 236.32 m, the total drilling time of 209.90 h, the average drilling speed per hour of 1.126 m/h, the highest rate of penetration of 1.19 m/h. The longest service life of a single bit was 91.86 h, and the highest footage drilled was 109.16 m (Table 7.10).

As the delivery of this type of reaming bit to the drill site was relatively late, only three drill bits were used in succession. Since KHAT drill bit lacked of gauge protection design on the bit body, the gauging capacity of this series of drill bit was affected. The contacting points between the bit and hole wall at hole bottom were only three points, when whirl of rock bit happened in the process of drilling, it would be easy to form a multi-petal hole profile, the actual hole diameter was slightly smaller.

Table 7.9 The statistics of KZ157/311.1 reaming bits

Serial num Dec of drill bit	Roundtrip	Footage drilled (m)	Drilling time (h)	Drilling speed (m/h)	Serial number of drill bit	Roundtrip	Footage drilled (m)	Drilling time (h)	Drilling speed (m/h)
KZ157/311.1-01	1	20.96	35.10	0.60	KZ157/311.1-15	2	136.53	97.00	1.41
KZ157/311.1-02	5	62.42	97.79	0.64	KZ157/311.1-16	1	70.23	73.99	0.95
KZ157/311.1-03	2	35.23	68.68	0.51	KZ157/311.1-17	1	82.77	65.08	1.27
KZ157/311.1-04	1	52.35	62.82	0.83	KZ157/311.1-18	1	68.59	55.82	1.23
KZ157/311.1-05	1	51.83	54.05	0.96	KZ157/311.1-19	1	89.00	68.93	1.29
KZ157/311.1-06	2	33.16	39.82	0.83	KZ157/311.1-20	1	62.14	36.46	1.70
KZ157/311.1-07	2	28.00	40.64	0.69	KZ157/311.1-21	1	96.65	64.49	1.50
KZ157/311.1-08	2	30.26	43.29	0.70	KZ157/311.1-22	1	98.71	70.95	1.39
KZ157/311.1-09	1	10.07	12.48	0.81	KZ157/311.1-23	1	97.66	91.31	1.07
KZ157/311.1-10	2	103.80	105.94	0.98	KZ157/311.1-24	1	107.74	75.54	1.43
KZ157/311.1-11	2	34.56	40.36	0.86	KZ157/311.1-25	1	18.13	17.38	1.04
KZ157/311.1-12	1	32.50	39.75	0.82	KZ157/311.1-26	1	69.57	64.76	1.07
KZ157/311.1-13	1	7.29	12.68	0.57	KZ157/311.1-27	1	15.60	18.35	0.85
KZ157/311.1-14	1	18.30	21.49	0.85	Total 27	38	1 534.05	1 474.95	1.04

Table 7.10 The statistics of KHAT157/311.1 reaming bit

Serial number of drill bit	Roundtrip	Footage drilled (m)	Actual drilling time (h)	Rate of penetration (m/h)
2002-A031	2	74.91	72.57	1.03
2002-A032	1	52.25	45.47	1.15
2002-A033	1	109.16	91.86	1.19
Total	4	236.32	209.90	1.13

When this type of bit was used, after a new bit was lowered to hole, it would need long time for redressing. After 236.32 m were drilled by three drill bits of this type and KZ type drill bit was used instead, hole section for redressing was even much longer, and it made the outer diameter of the new bit wear seriously when the new bit redressed to hole bottom, if drilling continued, and the wear of the outer diameter of the drill bit would increase continuously, then the outer diameter was far less than the standard outer diameter and lead to a conical-shape hole profile in the hole section drilled, therefore in the follow-up drilling, a longer distance redressing would be needed if a new bit was used again. This situation lasted to the end of reaming drilling. Finally, diamond reamer was added to the drilling tool, in combination with hole rectification in drilling or in special running-in for many times, an obvious effect was obtained.

3. **KZ157/244.5 reaming bit**

From the start of reaming drilling on October 29th, 2003 to the end of reaming drilling on March 14th, 2004, twenty one KZ 157/244.5 reaming rock bits were used. The total reaming footage drilled was 1059.34 m, the average rate of penetration was 1.09 m/h, and the highest rate of penetration was 1.53 m/h. The longest service life of a single bit was 91.85 h, and the highest footage was 107.06 m (Table 7.11).

Since the dog-leg degree in the small diameter hole trace in this reaming phase was big, and the bending moment borne by the pilot body of the reaming bit was large during reaming drilling, and at the same time, due to the tungsten carbide blocks, elastic steel pieces and other hard materials

Table 7.11 The statistics of KZ157/244.5 reaming bit

Series number of drill bit	Roundtrip	Footage drilled (m)	Drilling time (h)	Drilling speed (m/h)	Series number of drill bit	Roundtrip	Footage drilled (m)	Drilling time (h)	Drilling speed (m/h)
KZ157/244.5-01	1	6.53	6.99	0.93	KZ157/244.5-13	1	82.10	73.63	1.12
KZ157/244.5-02	1	19.12	18.60	1.03	KZ157/244.5-14	1	78.98	75.01	1.05
KZ157/244.5-03	2	5.69	4.64	1.23	KZ157/244.5-15	1	100.59	91.85	1.10
KZ157/244.5-04	1	31.90	42.56	0.75	KZ157/244.5-16	1	107.06	90.58	1.18
KZ157/244.5-05	1	7.63	15.58	0.49	KZ157/244.5-18	1	67.65	64.75	1.04
KZ157/244.5-06	1	17.25	12.83	1.34	KZ157/244.5-19	1	0.44	1.87	0.24
KZ157/244.5-07	1	73.85	54.01	1.37	KZ157/244.5-20	1	42.00	42.06	1.00
KZ157/244.5-08	1	91.00	59.39	1.53	KZ157/244.5-21	1	83.39	62.53	1.33
KZ157/244.5-10	2	49.22	50.21	0.98	KZ157/244.5-22	2	47.56	53.30	0.89
KZ157/244.5-11	1	50.03	51.90	0.96	KZ157/244.5-23	1	89.72	89.78	1.00
KZ157/244.5-12	1	7.64	7.41	1.03	Total 21	24	1 059.34	969.48	1.09

Fig. 7.20 Seriously worn pilot body in MH-2K-21 roundtrip

Fig. 7.21 Seriously worn pilot body in MH-2K-21 roundtrip

at hole bottom, the pilot position of the drill bit wore seriously (Fig. 7.20). In follow-up drilling, the pilot body of the bit run in again also bore big bending moment, with the same wear appeared. However, along with the increase of hole depth, the drilling tool gradually returned to the original hole axis under the guidance of the pilot body, with the wear disappeared.

4. **KHAT157/244.5 reaming bit**

The structure of KHAT157/244.5 bit basically followed the original structure of KHAT157/311.1, with specially designed cone legs adopted. In strengthening gauge protection capacity, tungsten carbides were inserted on the top of cone legs, however, due to inadequate tungsten carbides which were inserted at the same position direction in the circumference of the cones, the effect of gauge protection and rectifying well wall was unsatisfactory. As there was no cutting capacity at bottom, drilling could not be realized when foreign articles existed in the pilot hole. Another big problem was that the connecting area between bit pilot body and bit body was small in the design. Limited by this small size, the pilot body of the first drill bit broke and fell down to the hole bottom (Fig. 7.21), although no tungsten carbides

Table 7.12 Statistics of the application results of the pilot reaming drilling bits in the whole borehole

Reaming diameter (mm)	Type	Bit used	Total footage drilled (m)	Total drilling time (h)	Average footage drilled (m/bit)	Average service life (h/bit)	Average ROP (m/h)
157/311.1	KZ KHAT subtotal	27	1534.05	1475.95	56.82	54.66	1.04
		3	236.32	209.90	78.77	69.97	1.13
		30	1770.37	1685.54	59.01	56.16	1.05
157/244.5	KZ KHAT subtotal	21	1059.34	969.48	50.44	46.17	1.09
		1	86.12	86.16	86.12	86.16	1.00
		22	1145.46	1055.64	52.07	47.98	1.09
Total		52	2915.83	2740.49	56.07	52.70	1.06

Note Some KZ bits still could be used

were inserted at the front end and more space obtained. But the consideration to the strength in the design was still not enough (see right of Fig. 7.6). Other two drill bits were not used. The first bit drilled 86.12 m, drilling time was 86.16 h and the average drilling rate was 1.00 m/h.

5. **Summary of pilot reaming bits**

During two reaming drilling, four kinds of bits of two sizes and two types were used; statistics of the application effect of the bits can be found in Table 7.12. Among the bits used, most bits were KZ bits, mainly because the KZ bits had a stable performance, better gauge protection and safety in design, thus played an important role for the smooth accomplishment of the reaming drilling. Even though the average footage drilled and service life of the two kinds of KHAT reaming rock bit in the statistics were better, big problems still existed in gauge protection and safety, needing further improvement.