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THE DEVELOPMENT AND APPLICATION OF LIGHTWEIGHT ALPINE ICE CORING MECHANICAL RIG IN CHINA

GAO Xinsheng, ZHU Guocai, REN Jiawen, ZHANG Yongliang
(State Key Laboratory of Cryospheric Sciences, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou Gansu 730000, China)

Abstract
The past changes of climate and environment can be reconstruct through ice core study, which can provide the vital scientific proofs for thoroughly comprehending and predicting current and future changes of climate and environment . The ice core mechanical rig is as one of the essential tools to get ice core samples, which plays an important role in the acquisition of our alpine glacier ice core. This paper mainly introduces the development, application, problems, prospecting for future of our own designed ice core mechanical rigs for alpine glacier. Our own designed BZXJ rig is well performed, which is one of the best same kinds of rigs around the world, it has been drilled 125 ice cores and 8095m total thickness until the end of 2012, which has made important contributions in ice core research for our country .
Keywords: ice core rig; alpine glacier; development and application; China.

1 OUTLINE OF DEVELOPMENT OF ICE CORE MECHANICAL RIG IN FOREIGN COUNTRY

The information in ice cores became the best media to study biological, chemical, and physical processes in earth system because it is recorded with high resolution, abundant information, high reality, long table scale and high purity. Ice core study is an important method to reconstruct, monitor and predict the climatic and environmental changes in the past, current and future, which has already made a lot of important contributions for the study of international changes. Ice core study is a study hot point of the polar regions in nearly 30years, many large-scale ice core research program has completed in Arctic and Antarctic, the implementation of the research programs have made the polar ice core climatic and environmental study to a new stage.

The development of ice core study and ice drilling technology advances mutually depend on each other, ice drilling technology all over the world is along the constant pursuit of drilling depth, ensuring the ice quality (continuity, lossless), increasing the rate of penetration, around the main line of light-rig and adapted to the different natural environmental conditions and research projects to develop. Nowdays, there are 20 kinds of ice core rig system which have been applied and are being explored internationally. According to the depth, the ice core rig can be classified to shallow drilling, medium drilling and deep drilling; according to the methods of drilling, ice core rig can be classified to electric mechanical drill, thermal drill and hand drill.

There are some countries which are more advanced in ice core drill study such as the United States, Russia, Japan, France and Italy. American ice drill has been developed more than 50years,the level of technical staff who engaged in the study of ice drilling and the team have formed a scale, the design of shallow, medium and deep rig has become series. A number of important ice core projects have been carried out in Antarctic and Arctic, the length of the ice core drilled in the Arctic Greenland is 2537.36m, through the end; the depth in Antarctic Russia Vostok has been 3623m, 120m to the subglacial lake; France and Italy have drilled 3200m in Antarctic Dome C, through the end. Most of these vital ice core projects use the rig for the purpose of drilling in ice caps, ice sheets, and endeavor on how to improve the automation of drilling technology. Its original drilling mechanical principle is

binoculars stretched spring anti-torque device and most of the rigs used car to transport, which can't adapt to the request of the alpine glacier that is small volume, light weight, easy to operate and transport.

2 THE DESIGN OF ICE CORE MECHANICAL DRILL IN CHINA

Due to the narrow range of applications of ice core rig, there are no standardized products which can't be purchased through introduction or directly. In the end of 1988, the original Chinese Academy of Sciences Institute of Glaciology and Geocryology established ice core the mechanical rig design team, and manufacture in the small factories of this institute. Here only presents the development process of the rig, many experimental research and production will not be included.

2.1 The first version of the small diameter ice core mechanical rig

In 1989 based on the known materials, advantages of American CRREL shallow ice core drill and Japanese improved S-type binoculars drill, the design principles and ideas of Dermark lightweight shallow core drill and Australia glaciers shallow sampling drill, ice core mechanical design team aim the goal of ice core mechanical drill as the lightweight small diameter shallow ice core rig. Therefore, this drill choose monocular wing plate system, it was consist of winch, cable, electric control system, drill bit and motor. In August 1989, the sample drill (BZXF-I-A) was manufactured, the total weight of this drill was 130Kg, including the weight of drill bit 11Kg, and the heaviest part was winch, 70Kg, which included vertical pole, hard aluminum alloy wheel, 250m cable and motor.

Then we brought this drill to test on Glacier No.1 at Urumqi River, Tianshan in Xinjiang. Because the weather was too high, the water which was formed by melted firn and snow flew into the borehole, we need to test during nights time when 2:00 to 4:00 which was minus temperature. So we only got two cores, 10.6m and 16.4m respectively. This year drill with the expedition staff went to the Antarctic expedition, but due to the weather and ice fissure, the work terminated, the rig did not use.

In 1990, we produced another two improved new rig (BZXJ-1B), commonly known as small drill. The cable in winch added

Fig.1 Test drilling site on Glacier No. 1 at Urumqi River, Tianshan in 1989

Fig.2 Test core drilling site on Glacier No.1 at Urumqi River, Tianshanin 1990

to 300m, the design depth was 200m. We brought this drill to test on Glacier No.1 at Urumqi River, Tianshan again (Fig 2), drilled and got one 92m core through the end, totally

Table 1 Performances of 3 mechanical ice core drills

Type of drill rig		BZXJ – II B	BZXJ – II C	BZXJ – II D
Mechanical properties	Total height of mast/mm	2500	2500	3000
	Total length of drill/mm	1700	2350	2350
	Weight of drill/kg	11	19	21
	Rotational speed of inner barrel/rpm	40~50	40~50	40~50
	Length of inner barrel/mm	1100	1700	1750
	Drilling Time each run/s	45	105	150
	Drilling depth each run/mm	300~400	600	800
	Velocity of up and down of drill/(m per min)	25~30	25~30	25~30
	Surface assistive time each run/s	30	30	30
	Time of assembling rig/h	1.0	1.0	1.0
Ice core	Diameter of ice core/mm	64	92~94	95
	Average length of ice core each run/mm	300~400	700~800	700~800
	Outlook of ice core	Integral	Integral	Integral
	Recovery	Near 100%	Near 100%	Near 100%
Requirement of power	One phase gasoline generator/KW	2K	2.2	Ef2600Yamaha 2.2
	Starting power/W	500	1000	1000
	Practical power/W	200	150	500
Packaging	Material of outer package	Leather box	Wood box 1	Wood box 1
	Drilling Machine Net Weight/Kg	110	120	125
	Gross Weight/Kg	130	140	150
	Package pieces	4	3	3
	Volume/m^3	0.39	0.5	0.5

drilled 29h. In september 1991, this drill tested and drilled ice cores on King George Island in the Antarctic, it succeed in getting 25 cores, total length was 704m, the deepest on was 82m.

2.2 The first version of large diameter ice core mechanical rig

The samll diameter ice core mechanical rig(samll drill) drilled the core which couldn't meet the requirements of laboratory split sample quantity, so it's an urgent matter to develop large diameter ice core mechanical rig. In June 1996 we are devolved by the polar department of Ntional Ocean Council to design a piece of larger diameter shallow ice core rig (BZXJ – II A), which first used in the Antarctic ice sheet inland expedition, and completed the design and manufacture of the sample drill in this year. In October 1997 we tested on the field site and achieved great success. In 1998 during the expedition on Antarctic inland ice sheet, we improved the anti-torque wing plate of drill bit by increasing the length temporary and drilled two ice cores 100m and 82m, respectively.

2.3 The second version of large diameter ice core mechanical rig

In 2000,we started to improved the anti-torque wing plate by strentching the width and side knife by increasing its diameter, which greatly improved the ability of sneaking into the soft firn and snow layer, so the sencond verson of large diameter ice core mechanical(BZXJ-IIB)(Table 1) rig formed. In 2001during the Antarctic inland ice sheet exploration, we used BZXJ-IIB to drill 5 ice cores successfully, the cumulative length was 220m, the deepest one was 102m.

2.4 The third version of large diameter ice core mechanical rig

In 2001 we started to design the third version of large diameter ice core mechanical rig and use strenched spring rig which included four strenched springs ,when the drill down to

Fig.3 TestdrillingsiteonGlacierNo.1atUrumqi River, Tianshanin1997

the ice borehole the springs became a bow shape and tight to the bore wall to paly the role of anti-torque system. Compared with the wing plate anti-torque device, the strenched spring device without making grooves on the ice hole wall was safer,saved power and simplified producing .

In Octorber 2001 we succesfully developed a rig(BZXJ – II C) (Table 1), tests showed that it drilled 99 runs and took 8.6h to get 72.4m ice cores (through the end), which was excellent.

Fig.4 The fourth generation BZXJ styling ice core drill

2.5 The fourth version of large diameter ice core mechanical rig

In 2004 the fourth version of large diameter ice core mechanical rig developed as the dual-function rig (BZXJ-II D) (Table 1) was using currently, it gathered the function of the first, second and third version rigs, it could choose one of the function which depended on the condition of the firn and snow layer and drill very fast and get the ice core safely (Fig. 4). The fourth version of large diameter ice core mechanical rig could drill all the encountered firn and snow layers, it was excellent on weight, volume, transportation, installation, operation, power consumption, coring speed and other aspects, especially suitable for high glaciers and polar ice caps line exploration.

2.6 The design of 500m ice core rig

In 1995, the Chinese Academy of Sciences issued a 500m ice core drilling rig project which was developed and implemented by Chinese Academy of Sciences Institute of Glaciology and Geocryology ice core department. In October 1998 it was tested on Glacier No.1 at Urumqi River, Tianshan and

Antarctic inland ice sheet, after that it was improved and drilled more than 50m.

2.7 The design of 20m hand shallow rig

Hand drill was a kind of rig which was totally depended on human recourse to pull drill up and down and adapt to both the battery pack and generator power, it (BZXJ – I C)was developed based on the small diameter ice drilling rig BZXJ-I B.

BZXJ-I C drill rig was consist of drill bit, drill tube, cable, batteries, control box, total weight was 15Kg.This drill with batteries could drill 20m depth of shallow layers and get 68mm diameter of ice core. If it was powered by generator (model EF1000i, weight 14Kg), the cores were not limited.

This rig was portable and drilled 24 shallow ice cores on the Qinghai-Tibet Plateau glaciers , Arctic glaciers and Antarctic ice sheet line exploration, cumulative depth was 44m. it could operate by one person and drill one 20m ice core in 4h.

3 THE APPLICATION OF ICE CORE MECHANICAL RIG

Since 1989 to the end of 2012, BZXJ rig drilled 8095m cumulatively (including the quantity of the hand rig), and got 125 ice cores totally (including 37 cores which was through the end) (Table 2). The depth of the deepest ice core which was through the end was 173m (Tigers ditch on the 12th glaciers east branch firn basin),the deepest ice core was 189.4m (Tanggula glaciers), the highest position coring altitude was 7050m (tomb of Shi Tage peak glacier), in western of China Tianshan,Kunlun,Tanggula ,Nyainqentanglha, Himalaya Mountains and the Pamirs, the glaciers which were implemented the coring program were total 27 lines and succeeded in achieving the success rate of through the end of ice core to 78 %.

Based on several ice coring drilling practice, the statistics of time used for drilling different depth's ice core were shown on Table 3, which can give a reference for reasonable arrangements of drilling and logistical preparation time in the field. Controlling the rig is a kind of high technical work which need the operators go through specialized training and multiple drilling practice to learn correctly with the adjustment of the drill, drilling technology of different firn and snow layer, the ability of eliminating blocking problems, maintenance of the mechanical parts of rig. Table s lists the data of drilling results when the rig is in better condition, we don't need to pursuit the penetration speed in normal operation, but to ensure the safety of rig.

4 THE PROBLEMS AND PROSPECTS OF THE RIG

With the continuous increases of the global temperature, most of the mountain glaciers have been changed from cold glaciers to warm glaciers, glacier firn basin surface appeared cracks, the melt water penetrate into the inside of the ice during summer season, which formed a local high temperature zone, even the ice layer which is close to the bottom of the glacier ice was in pressure financial state, ice is high in moisture. For such kind of ice the common BZXJ rig can't equal to this work. Besides the current ice core research want to obtain a small amount of the bedrock samples of the bottom of the glacier to provided new proofs for the off year, due to the rig didn't design the special drill bits, now it can't obtain bedrock samples.

How to solve the above problems need to develop a king of sealed mechanical ice core drill which can drill in ice hole which contains melt water in order to ensure the penetration rate and the quality of ice core, overcome the disadvantages of elecrothermal ice coring drill. It is a new research work to drill a small amount of bedrock samples in ice hole which need to ensure the security of the drilling and at the same time overcome the negative effects of heat of the drill bit, the most difficult problem is how to break bedrock and bring it to the ice surface. We hope we can support by some technical force in the future as soon as possible to start this research work.

Table2 Ice core drilling list obtained by BZXJ mechanical drills in 1989-2012

No.	Time/(Year-month)	Drilling site	Operator	Drilling depth/m	Cumulative depth/m
1	1989-08	Xinjiang Tianshan No. 1glacier	高新生	16.4/10.6	27
2	1990-10	Xinjiang Tianshan No. 1glacier	高新生、张永亮	57/92 *	147
3	1991-1992	Antarctic Great Wall Station Collins ice cap	高新生	82/60/60 / ... 25	704
4	1992-07	Xixiabangmakongwo hot glacier	张永亮	13/45 *	58
5	1991-05	Kunlun Chongce ice cap	张永亮	52 *	52
6	1996-06	Xinjiang Tianshan No. 1glacier	高新生、张永亮	85 *	85
7	1996-10	Antarctic inland ice sheet First exploration	高新生	50/50	100
8	1997-1998	Antarctic inland ice sheet exploration	张永亮	50	50
9	1998-05	East velvet cloth glacier	张永亮	84	84
10	1998-1999	Antarctic inland ice sheet exploration	高新生、张永亮	100/80	180
11	1999-05	Hoh Malan glacial	张永亮	101	101
12	1999-07	Nyainqentanglha glacier	高新生	30	30
13	2000-10	Tibet Puruogangri ice	高新生、张永亮	40/84/157 *	281
14	2001-05	East velvet cloth glacier	张永亮	117 *	117
15	2001-08	Mushitage glacier	张永亮	70	70
16	2001-10	Xinjiang Tianshan No. 1glacier	高新生	70 *	70
17	2001-10	Xinjiang Tianshan No. 1glacier	高新生、张永亮	54	54
18	2001-11	Antarctic inland ice sheet exploration	高新生	102/20/20/20/20/20	202
19	2002-04	Qilian Dunder ice cap	高新生	50/40/30/15	135
20	2002-08	Mushitage glacier	张永亮	10/50/90/78 *	228
21	2002-10	Everest East Rongbuk Glacier	张永亮	40/95 * / 109 *	244
22	2003-08	Mushitage glacier	张永亮	50/54.8 *	105
23	2003-10	Nyainqentanglha glacier	张永亮	* 105.5 / 123.8 *	229
24	2003-11	Antarctic expedition Amery Ice Shelf	高新生	301.9	302
25	2004-04	Tibet Puruogangri ice	高新生	80	80
26	2004-04	Glasgow Dandong glacier	张永亮	87/10/15 *	112
27	2004-05	Tanggula glacier	张永亮	189.4	189
28	2004-2005	Antarctic inland ice sheet exploration	张永亮	100	100
29	2004-06	Abroad（New Zealand mountain glaciers）	高新生	52/37/35/30/28	176
30	2005-04	Tibet Don Gula Mountains	高新生、张永亮	32/130.8 *	162.8
31	2005-04-05	Qinghai Animaqing Snow mountain	高新生	56/17	73

Table2 Ice core drilling list obtained by BZXJ mechanical drills in 1989-2012

No.	Time/(Year-month)	Drilling site	Operator	Drilling depth/m	Cumulative depth/m
32	2005-09	Himalayan glaciers gifted Chelsea	张永亮	67.5 * / 66 *	134
33	2005-08	Xinjiang Tianshan Miaoergou glacier	高新生	60 * / 58 *	118
34	2006-04	Kunlun jade Everest glacier	张永亮	21/125.5 *	147
35	2006-05	Tibet's glaciers Southeast Day Lombardy	高新生	30/30/35	150
36	2006-05	Qilian eighty-one glacier	张永亮	93.3 * / 56.7 *	150
37	2006-09	Glaciers in Tibet Langkazi	高新生	60 *	90
38	2006-10	Glasgow Dandong glacier	张永亮	78/145	223
39	2007-04	Color Tei glacier	张永亮	17/65 *	82
40	2007-05	Tibet's Southeast Day Lombardy glaciers	高新生	30	30
41	2007-05	Jade Everest glacier	张永亮	45/121.6 *	167
42	2007-09	Subei victory glacier in Qilian Mountains	高新生	90 *	90
43	2009-04	Tibet color Kangri glacier	张永亮	127.77 * 126 *	254
44	2008-06	Abroad（Mongolian mountain glaciers）	高新生	41	41
45	2009-09	Abroad（New Zealand mountain glaciers）	高新生	45/31 * / 30/25/10	141
46	2009-11	Xinjiang Tianshan No. 1glacier	高新生、张永亮	60 *	60
47	2011-05	Qinghai Pingdingshan glacier	张永亮	59.28 * / 57.8 * / 81 *	200
48	2011-06	Xinjiang MUZTAG glaciers	高新生	40	40
49	2011-09	Xinjiang wood Kat Heung glacier	张永亮	32.6 * 32.4 *	65
50	2011-10	Glaciers in Qilian Mountains Laohugou	高新生、张永亮	166/173 *	339
51	2012-04	Mu Zi tower grid glacier	张永亮	166	166
52	2012-06-08	Xinjiang Kuokuosele glacier	张永亮	188/38/170	396
53	2012-10-11	Kunlun Chong side glacier	张永亮	132*/135*/59	326
54	2001-2011	Hand auger shallow drill ice coring		24	440
	合计			125	8397

Table 3 Drilling depth with spending time

Depth zone /m	Weighted average speed/Minimal coring speed /(m·h^{-1})	Required time /h	Cumulative time /h
0 ~ 20	13.3 /	1.5	1.5
20 ~ 50	9.5/8.2	3.2/3.7	4.7/5.2
50 ~ 100	6.3/5.4	8.0/9.2	12.7/14.4
100 ~ 150	4.4/4.0	11.2/12.5	23.9/26.9
150 ~ 200	3.4/3.2	14.5/15.6	38.4/42.5