Development of 7,000m Class ROV *KAIKO7000*

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ABSTRACT

ROV *KAIKO* has achieved 20 dives to the Mariana Trench Challenger Deep. However, the *KAIKO* lost her vehicle through a snapping of the secondary cable on May 29th 2003. JAMSTEC immediately established the Committee for the Investigation of Accident.

At the same time, JAMSTEC started the development of *KAIKO7000*, which was to remodel the 7,000m class thin fiber-optic cable ROV *UROV7K* as a vehicle. This is a temporary system, which will be replaced by the new developing 10,000m class ROV.

KAIKO7000 started its research cruises on April 2005. This paper introduces the development and cruises of *KAIKO7000*.

INTRODUCTION

In 1993, JAMSTEC developed 10,000m class ROV *KAIKO* (Fig.1and 2).

KAIKO had dive to the Challenger Deep up to 20 times since 1995.

The *KAIKO* system comprises of R/V"KAIREI", "Launcher" and "Vehicle".

On the Launcher, which is a Tether Management System (TMS), 250m long secondary cable and winch, CTD, TV camera, side scan sonar and sub-bottom profiler are installed.

On the Vehicle, the seven-function manipulator for both hands made of titanium, the hydraulic thrusters (4x horizontal: 4.9kW each, 3x vertical: 5.2kW each), the panorama view color TV camera which was one set by three cameras, one 3-CCD camera and optical still camera are installed.

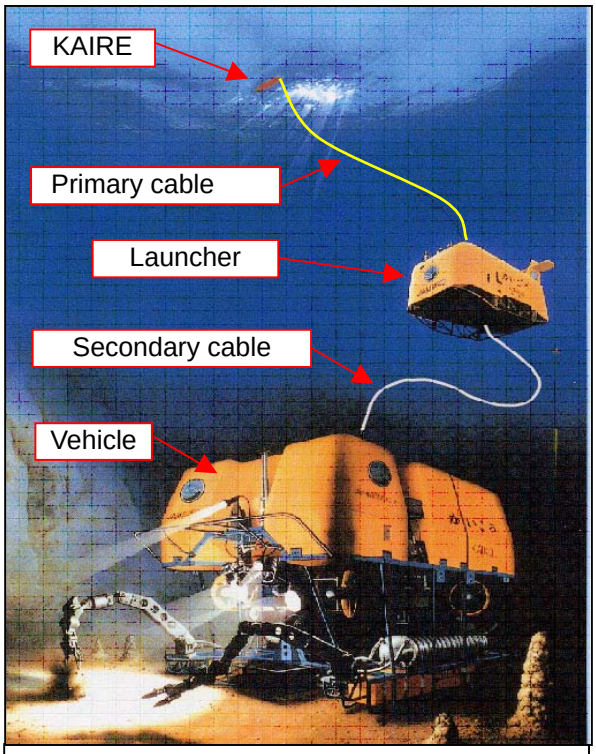

Fig.1: Image of the original *KAIKO* system

In May 29th 2003, *KAIKO* had completed the 296th dive at a depth of 4,657m in the Nankai Trough 130km southeast off Cape Muroto in Shikoku Island. After we had recovered bore hole data from ODP Hole 808-I we tried to reel in the secondary cable to mate the Launcher and Vehicle.

However, they could not be mated. Then, optical communications were shut down, and the main power supply was shut down. Immediately, the primary cable was reeled in for the *KAIKO* recovery.

When the launcher was recovered on surface,

we knew that the Vehicle was lost.
All the crew and shore supporting staffs worked for the discovery of the Vehicle. However, We could not find the Vehicle.
JAMSTEC had established the Committee for the Investigation of Accident.
They investigated cause of the accident and reported to JAMSTEC including recommendations for the safety operation.
Development of *KAIKO7000* (Fig.4) was carried out by JAMSTEC.

Fig. 2: *KAIKO*

Fig. 3: *UROV7K*

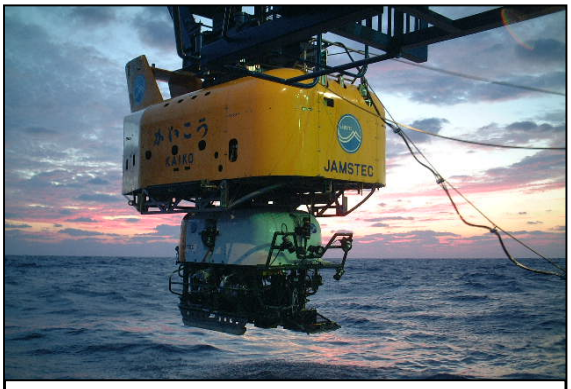

Fig.4: *KAIKO7000*

UROV7K (Fig.3) was developed in 1998 and it reached to depth of 3,700m until that time. *UROV7K* had the battery power source and it was connected to the support vessel with optical fiber cable of 1mm in diameter. A large cable handling system was not needed because of very thin cable. Operation time was limited depending on the battery, but *UROV7K* could move well with small thrust power because the thin cable had almost no cable drug. The vehicle needs no large electric motor and thrusters, and very compact system is the characteristic feature of the *UROV7K*. Consequently, main mission of the *UROV7K* was observation with TV cameras and a light work with a simple manipulator.

MODIFICATION OF UROV7K TO KAIKO7000

KAIKO and *UROV7K* had been designed by different concepts.
Modification of the *UROV7K* to *KAIKO* vehicle required a great change of the main parts.

Table 1. Feature of *KAIKO* and *KAIKO7000*

Item	*KAIKO* Vehicle	*KAIKO7000* Vehicle
Operating depth	11,000m	7,000m
Dimensions	3.1L, 2.0W, 2.3H (m)	2.8L, 1.8W, 2.0H (m)
Weight in air	5.5 ton	2.9 ton
Power source	From R/V *KAIREI* through Launcher (3phase AC3000V)	
Cable	Secondary cable 29.5mm O.D.	
Propulsion	Horizontal: 4.9kW(4) Vertical: 5.2kW(3)	Forward-Back: 0.8kW(4) Right-Left: 0.8kW(2) Vertical: 0.8kW(4)
Fiber optic	Multi mode	
TV camera	Color TV:3 3-CCD color: 1 B/W: 1	Color TV: 2(P/T) 3-CCD color: 1 B/W: 1
Still camera	Optical (1)	Digital, 5M pixel (1)
Manipulator	7 function Both hands Master-slave control Lift capacity: 25kg	6 function Single hand Rate control Lift capacity: 40kg
Pay load	150kg (in air) 100kg (in water)	30kg (in water)
Light	Halogen: 500W (5) HID: 400W (2)	Halogen: 500W(2) 250W(1) HID: 400W (1)
CTD	None	SBE-49(1)
Other devices	Altitude meter (1), Depth meter (1) Fiber optic gyro (1), OAS (1)	
Transponder	Responder(1)	Responder/Transponder(1) Transponder(1)
Safety devices	Radio beacon(1) Flasher(1) Ballast Releaser(1)	Argos(1) Argos w/ GPS(1) Flasher(1) Ballast Releaser(2)
	Launcher	
Operating depth	11,000m	
Dimensions	5.2L, 2.6W, 2.0H (m)	
Weight in air	5.3 ton	
Main Equipment	Side Scan Sonar(1pair)/ Sub-bottom profiler(1)/ CTD(1)/ OAS(1)/ LBL wave interceptor(1)/ SSBL wave interceptor array(1)/ Responder(1)/ Secondary cable handling system(1)/ Vehicle-Launcher linkage system(1)/ etc.	
	Primary Cable	
Specification	Length: 12,500m/ Outside diameter: 45mm	
	Secondary Cable	
Specification	Length: 250m/ Outside diameter: 29.5mm	

Table 2 and Fig.6 show modifications from *UROV7K* to *KAIKO7000*.

Table 2. Remodeling points from *URO7K*

Item	Remodeling Points
Power Source	Remove the battery, Install the Electronic transformer (100VDC), and Isolated transformer (1 ϕ 240VAC)
Thrusters	Add 6 thrusters, Total 10 Thrusters
Manipulator	Replace from 5 function to 6 function
Fiber optics	Change from single mode to multi mode Increase control lines for additional devices
Pay load	30Kg in water, add the power and control lines
Light	Add HID light
Safety measure	Ballast releasers (2), Transponders (2) Argos transmitters (2)
As for Launcher	Installed remote controlled circuit breaker (For 3 ϕ 3000VAC)

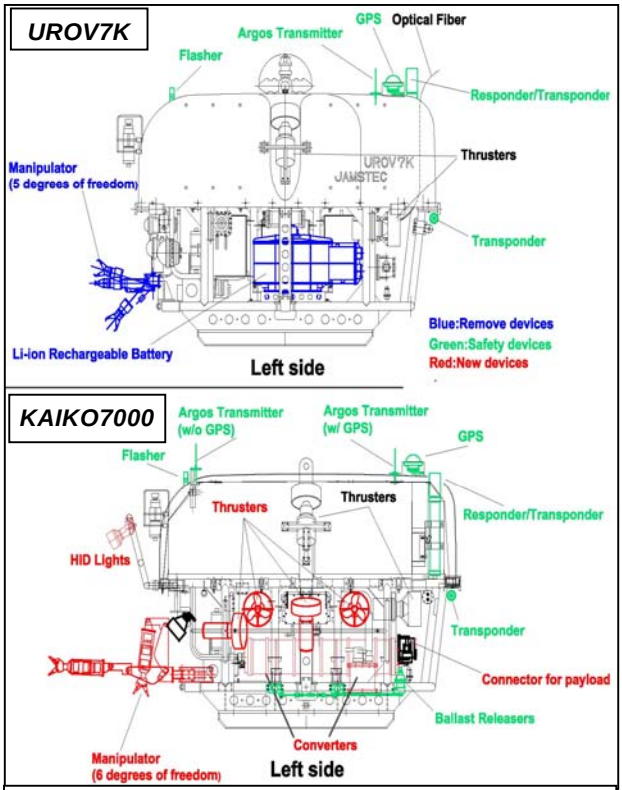

Fig.6: Out line of modification points

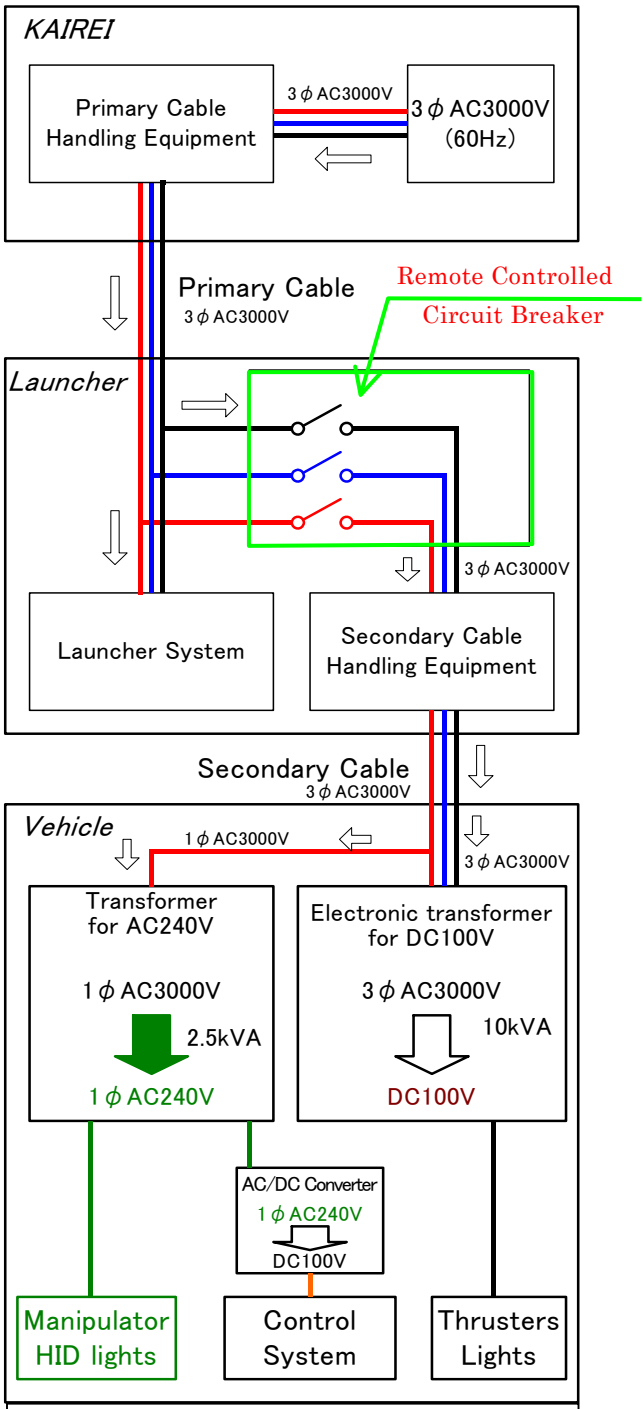

Fig.7: Main power supply systems

As shown in Fig 7, *KAIKO7000* replaced main power supply system from lithium-ion rechargeable battery to three-phase 3000VAC through the Launcher by KAIREI.

Because *UROV7K* battery had not enough power, to carry out long time missions and heavy work in deep sea. The battery could be supplied 100VDC and 60Ah(30Ah X 2 units). *KAIKO7000* system required single-phase 240VAC and a lot of 100VDC power.

We decided to use an electronic transformer that could be able to convert directly from three-phase 3000VAC to 100VDC of 20kVA.

The electronic transformer developed in

JAMSTEC was very light compared with a normal coiled transformer. Also, another coiled transformer supplied single-phase 240VAC.

An Improvement for Safety Measures

KAIKO was supplied with three-phase 3000VAC from support ship to the Vehicle that was directly connected through the Launcher.
Therefore, when the Vehicle power supply was shut down, the Launcher power supply also stopped. This will give a serious damage for *KAIKO* system, because it is not possible to reel in the secondary cable, which will result in the damage of the secondary cable during recovery.
KAIKO7000 installed remote controlled circuit breaker on the Launcher.
Thus, the Launcher got an independent power supply from the Vehicle.

Remodeling the Thrusters

UROV7K had enough maneuverability with four electric thrusters
(2 x horizontal, 2 x vertical: 0.8kW each).
However, *KAIKOU7000* needed thrust power, which would be able to withstand against the drag by the secondary cable.
Consequently, *KAIKO7000* installed additional six thrusters to increase thrust power.

Light and Manipulator, etc.

On the Vehicle, add one more HID light and replaced manipulator from five-function to six-function. Replaced new manipulator could handle many complicated work.
And, safety measures add, too.

Method for Mating (Fig.8)

Mating of the Vehicle with the Launcher has been one of the most important operations for the safety of the *KAIKO* system, which is the same with the *KAIKO7000* as well.
However, the *KAIO* vehicle and *UROV7K* had totally different structure of their mainframe.

We developed new mating system for the Launcher and the Vehicle.

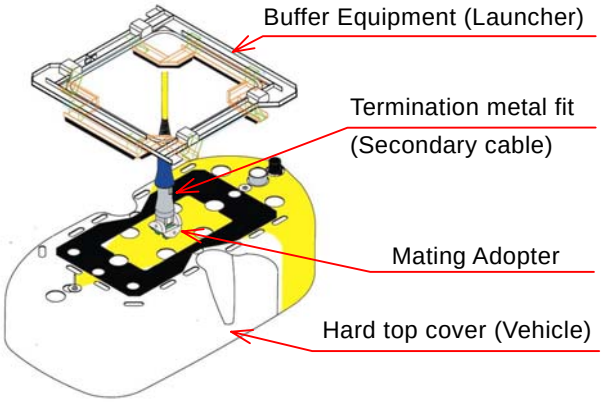

Fig.8: New Mating Method

The remodeling had completed in a short time between July 2003 and March 2004.

SEA TRIALS

The *KAIKO7000* started sea trial from April 2004. Five sea trials had been carried out until the end of March 2005.
In the 1st and the 2nd sea trial, the Vehicle control system was affected by harmful noise that was created by new electronic transformer.
In the 3rd sea trial, dive to depth of 7,031m was achieved. However, system did not worked perfectly. For example, OAS and thruster were still under the influence of the noise.
Each problem in the sea trials was fixed step by step.
KAIKO7000 worked perfectly during 5th sea trial in March 2005.
Sampling work at a depth of 7,000m and recovery of the mooring system by cutting mooring rope was successful (Fig.9, and 10).

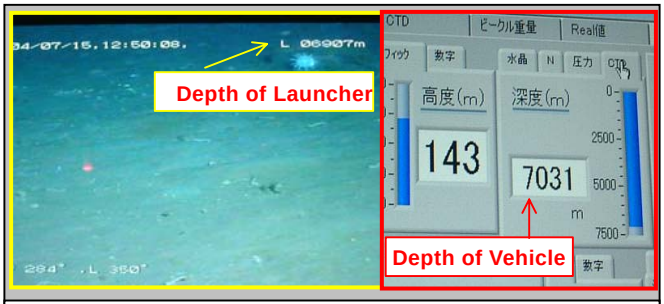

Fig.9: At 3rd Sea Trial (The Japan Trench)

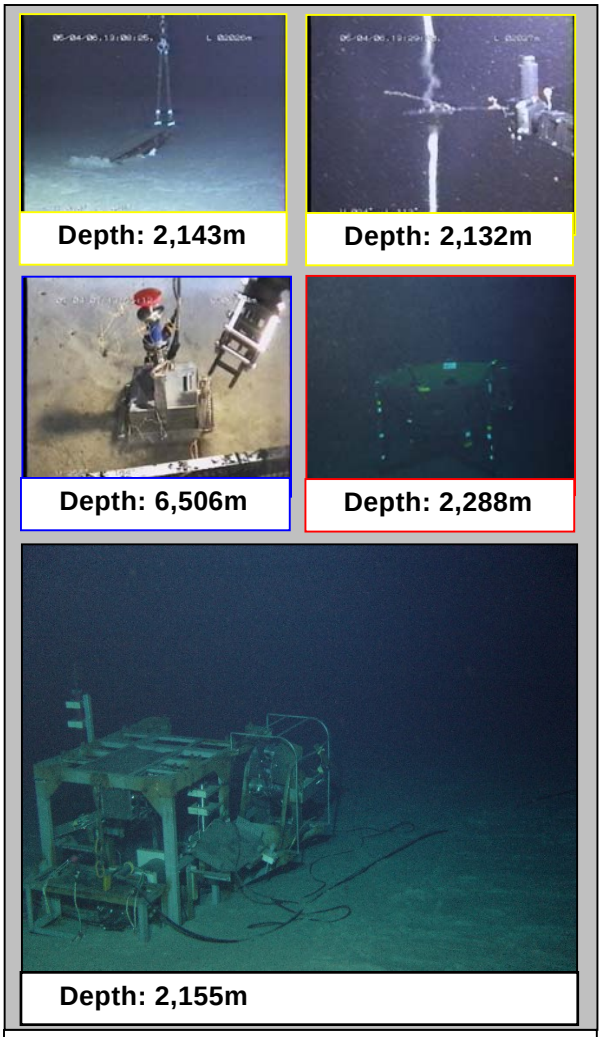

Fig.10: At 5th Sea Trial（Off. OKINAWA Is.）

Table 3. Results of Sea Trials

1st-term	**-April, 2004 (Combined L/V)**	
Sagami Bay	Depth: about 1,000m	3 dives
2nd-term	**-May, 2004 (Combined L/V)**	
Sagami Bay	Depth: about 1,000m	4 dives
3rd-term	**-July, 2004 (Separate L/V)**	
Sagami Bay	Depth: about 1,000m	3 dives
Nankai Trough	Depth: 3,579m	1 dive
The Japan Trench	Depth: 7,031m	1 dive
On Berth Test	**-November, 2004(Vehicle only)**	
in JAMSTEC	Hanging from shore	1 time
4th-term	**-November, 2004 (Separate L/V)**	
Shikoku Basin	Depth: about 4,900m	1 dive
5th-term	**-March, 2005 (Separate L/V)**	
Okinawa Off	Depth:Max.7,053m	14 dives

RESEARCH CRUISES

Development of *KAIKO7000* was completed through the five sea trials until the end of March 2005. *KAIKO7000* had debuted on research cruise from May 2005.

We achieved successful operations in three cruises.

At the Japan Trench, the *KAIKO7000* recovered the seismic measuring system on the sea floor at 6,000m depth.

And, we recovered a data recorder from seismic measuring platform in 5,700m depth at the Northwest Pacific Ocean.

As for the underwater works, it was recognized that there were several insufficient aspects.

For example, the manipulator was single hand while KAIKO had dual hands, and the maximum payload capacity reduced from 100kg to 30kg in water.

We will add one more manipulator, will increase the thrust power and will make a new main frame in order to adopt above requirements.

This modification will be completed until April 2006.

CONCLUSIONS

Modifications of *UROV7K* and development of *KAIKO7000* were completed in a short period about 9 month and low cost.

Performance of the *KAIKO7000* is almost perfect. However, when we compare with the original *KAIKO*, we need further improvements.

As, KAIKO7000 is temporary vehicle, we expect to develop the new full ocean depth *KAIKO* as soon as possible.

REFERENCES

Momma, H., Watanabe, M., Hashimoto, K., and Tashiro, S., (2004) “Loss of the Full Ocean Depth ROV Kaiko – part 1: ROV Kaiko – A Review,” *Proc 14th Int Offshore and Polar Eng Conf*, Toulon, France ISOPE, Vol 2, pp. 191-193.

Tashiro, S., Watanabe, M., and Momma, H., (2004) “Loss of the Full Ocean Depth ROV Kaiko – Part 2: Search for the ROV Kaiko Vehicle,” *Proc 14th Int Offshore and Polar Eng*

Conf, Toulon, France ISOPE, Vol 2, pp. 194-198.

Watanabe, M., Tashiro, S., and Momma, H., (2004) “Loss of the Full Ocean Depth ROV Kaiko – Part 3: The Cause of Secondary Cable Fracture,” *Proc 14th Int Offshore and Polar Eng Conf*, Toulon, France ISOPE, Vol 2, pp. 199-202.

Murashima, T., Aoki, T., Tsukioka, S., Hyakudome, T., Yoshida, H., Nakajyo, H., et al. (2003) “Thin Cable System for ROV and AUV in JAMSTEC,”
MTS/IEEE *Oceans 2003*.

Murashima, T., Aoki, T., Nakajyo, H., Tsukioka, S., and Asao, Y., (1999)
“OPTICAL COMMUNICATION SYSTEM FOR EXPENDABLE FIBER OPTICS ROV “UROV7K” SYSTEM,” *Proc 9th Int Offshore and Polar Eng Conf*, Brest, France, ISOPE, Vol 4, pp 628-634.

Murashima, T., Nakajyo, H., Yoshida, H., Yamauchi, N., and Sezoko, H., (2004)
“7,000m class ROV *KAIKO7000*,”
MTS/IEEE *Oceans 2004*, Kobe, Japan.

Murashima, T., Nakajyo, H., Yoshida, H., Yamauchi, N., and Sezoko, H.,(2004)
“The Development and Sea Trial of KAIKO7000,”*Int Offshore and Polar Eng Conf*, Soul, Korea, ISOPE.