Awards on iMQL®
(a) 23rd Grand prix of invention, Onitsuka invention & performance award in 1998.
(b) 19th Performance award of Science and Technology Promotion in 1999.
(c) Technical award of Japan Society for Precision Engineering in 2001.
(d) 33rd New technology award of Japan Society for the Promotion of Machine Industry in 2003.

Reference

(1) Sessakuyuzai handbook, Kogyo-chosa-kai, ISBN4-7693-2173-2 C3053 (2004)
(2) S.Ikawa, Mechanical Engineering, vol.47.5 (1999)
(3) ECCJ, Award (2002)
(4) The Mainichi Newspapers, article on March 16th (1998)
(5) F.Klocke, Annals of the CIRP, vol.46, 2(1997)
(6) K.Weinert, Annals of the CIRP, vol.53, 2(2004)
(7) INPIT, Report (2005)
(8) JMTBA, Report (2004)
(9) T.Makiyama, A study on MQL machining for machine tool, Hiroshima University (2008)
(10) H.Yokota, Journal of JSPE, Vol.68, No.7 (2002)
(11) H.Yoshimura, Tool engineer, vol. 47, 7 (2003)
(12) Machinery lubrication, vol.4 (2008)
(13) Final report of CTMA/NCMS Consortium, Pilot Study of Near-Dry Machining Phase 1(2003)

HORKOS CORP

Head Office & Plant	2-24-20 kusado-cho, Fukuyama City,Hiroshima 720-8650, Japan	Tel:+81-84-922-2835 Fax:+81-84-922-2609
Fukuyama North Plant	1613-50 Hojoji, Ekiya-cho, Fukuyama City, Hiroshima 720-2413, Japan	Tel:+81-84-949-3701 Fax:+81-84-949-3702
Kohriyama Plant	56-6, Aza Ishizuka, Kohriyama City, Hiroshima 720-2413, Jappan	Tel:+81-24-943-5501 Fax:+81-24-941-3602
Tokyo Branch	3-28-5 Nakarokugo, Ota-ku, Tokyo 144-0055, Japan	Tel:+81-3-3735-5831 Fax:+81-3-3735-5830
Ohmiya Business Office	1-63-1 Dote-cho, Ohmiya-ku, Saitama City, Saitama 330-0801, Japan	Tel:+81-48-645-2681 Fax:+81-48-644-5230
Shizuoka Business Office	3-10-26 Nakata Suruga-ku, Shizuoka-City, Shizuoka 422-8041, Japan	Tel:+81-54-203-5341 Fax:+81-54-203-5346
Nagoya Branch	4/23 Harusato-cho, Chikusa-ku, Nagoya City, Aichi 464-0038, Japan	Tel:+81-52-764-3900 Fax:+81-52-764-3911
Kariya Business Office	2-14-10 Honbayashi, Yata-cho, Chiryu City, Aichi 472-0015, Japan	Tel:+81-566-83-2253 Fax:+81-566-83-2263
Osaka Branch	Akashiya Building, 3-5-4 Nishitenma, Kita-ku, Osaka 530-0047, Japan	Tel:+81-6-6364-7906 Fax:+81-6-6364-7904
Hiroshima Branch	Hiroshima Office Center Building, 3-35 Higashikojin-cho,Minami-ku, Hiroshima 732-0805, Japan	Tel:+81-82-264-2527 Fax:+81-82-263-0385
Detroit Branch HTCA HORKOS TECHNICAL CENTER OF AMERICA INC.	8655 Ronda Drive, Canton, Michigan 48187 USA	Tel +1-734-354-7940 Fax +1-734-354-7939
Bangkok Branch HORKOS(THAILAND) CO.,LTD	7th Floor Unit B Zone B Sino-Thai Tower 32/38 Sukhumvit 21 Road(Soi Asoke) Khwang Klogtoey Nua. Khet Wattana. Bangkok 10110	Tel +66-2-665-7182 Fax +66-2-665-7183
Dusseldorf Business Office	Ispingrade 12, 42477 Radevormwald,Germany	Tel +49-2195-68 49 760 Fax +49-2195-68 49 770

Sapporo Business Office, Sendai Business Office, Kohriyama Business Office, Maebashi Business Office, Tokyo Higashi Business Office, Tama Business Office
Chiba Business Office, Yokohama Business Office, Kanazawa Business Office, Kyoto Business Office, Osaka Minami Business Office, Kobe Business Office
Takamatsu Business Office, Okayama Business Office, Fukuoka Business Office, Kitakyusyu Business Office, Kagoshima Business Office

UKAS QUALITY MANAGEMENT 105 | UKAS ENVIRONMENTAL MANAGEMENT 105 | JAB CM025 | ANAB ACCREDITED | PERRY JOHNSON REGISTRARS, INC.

"ISO 9001:2008 ISO14001:2004 Certificate Division

·Head office	Machine Tool Dept.	· Environment Improving Equipment Dept.
·Fukuyama-kita Plant		
·Tokyo Branch	Machine Tool Dept.	· Environment Improving Equipment Dept.
·Omiya Business Office	Machine Tool Dept.	
·Shizuoka Business Office	Machine Tool Dept.	
·Kariya Business Office	Machine Tool Dept.	· Environment Improving Equipment Dept.
·Osaka Branch	Machine Tool Dept.	· Environment Improving Equipment Dept.
·Hiroshima Branch	Machine Tool Dept.	· Environment Improving Equipment Dept.
·Fukuyama Business Office	Environment Improving Equipment Dept.	
·Okayama Business Office	Environment Improving Equipment Dept.	
·Fukuoka Business Office	Environment Improving Equipment Dept.	

URL http://www.horkos.co.jp

NOTE: The specifications and drawings in this catalog are subject to change without notice.
The information in this catalog is as of October 2010.
"iMQL" are registered trademarks of HORKOS Corporation.
The export from Japan of this product is subject to an authorization from the Japanese government.

Economy & Ecology
2125.1010N
Printed in Japan
18 October 2010

HORKOS

GO GREEN
WITH HORKOS

iMQL Minimum Quantity Lubrication Internal Mixing System ®

Machining machine tool innovation by iMQL® system

- 21st century new technology dedicated for high efficiency machining, energy saving, saving natural source and environment conservation with reducing the cutting liquid considerably -

HORKOS CORP

PART1 GENERAL STATEMENT

◆Technical background

It is essential to have the added-value of the industrial products for enrich our daily life since Japanese natural resource is quite limited. The added value of the industrial products advances depending on its shape accuracy and quality of finished face . Cutting work is the processing method the most used for realization of the high precision products. It has been commonly known that for improving the productivity of cutting work, the wet cutting method is positively taken from the past [(1)]. For enhancement of such productivity, the quantity of coolant and supply pressure had been becoming enlarged. As a result, negative side of coolant has come up to surface as in the following points;

At machining plant, 80% of consumption energy is from processing machines. Of them, more than 50% is for providing the Coolant (cutting liquid) (Fig.1) [(2)]. It is noticeable that its quantity is around 2.7 times as much than that of spindle directly producing the cutting chip. It is also reported that 32% of all waste products brought from automobile factory into incineration disposal plant is used cutting liquid [(3)]. Some chemical materials are used for cutting liquid to enhance the cutting performance. They include the hazardous materials carcinogens or endocrine disrupter which we learned recently. Recently in Japan, it is brought up that chlorine-based cutting liquid ingenerates dioxin at high concentrations [(4)], and was excluded from the JIS regulation. Awareness of environmental issues and health and safety for workers have been increasing year by year, and legal regulation is getting stricter [(1)]. It is said that maintenance cost of cutting liquid at automobile factory is 7-17% of overall cost. It is several times as much as cutting tool cost (2-4% of all cost) which was usually seen as problem of factory management (Fig.2) [(5)]. Therefore, negative side of cutting liquid has been problem on cost and this should be solved.

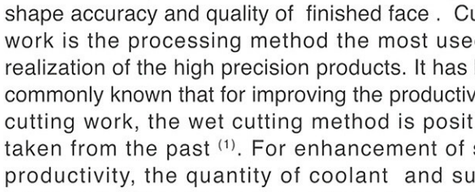


Fig. 1 Energy consumption ratio of cutting machine[(2)]

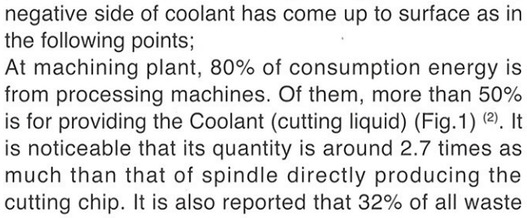


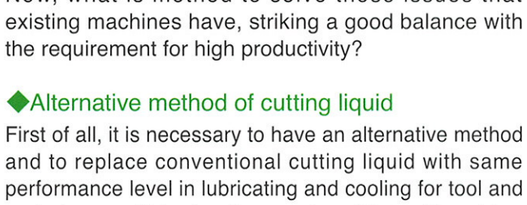
Fig. 2 Cost breakout of cutting liquid[(5)]

Now, what is method to solve these issues that existing machines have, striking a good balance with the requirement for high productivity?

◆Alternative method of cutting liquid

First of all, it is necessary to have an alternative method and to replace conventional cutting liquid with same performance level in lubricating and cooling for tool and workpiece, and blowing down and washing cutting chips. Recently Heat hardiness and frictional coefficienty had been improved along with the coating technological advancement. Also a trial of providing specific gas into machining point for having the same advantage has been taken. Those dry cutting method is the most ideal for dry cutting method in the purpose of elimination using the cutting liquid. But they have still problems on tool life performance and machining efficiency and have limited use in practice.

Therefore, there would be a method such as; to provide a very little of high lubricating performance cutting liquid as oil mist with compressed air into the machining area for lubricating and cooling the machining point (Fig. 3). This method is called MQL (Minimum Quantity Lubrication) and regarded as new cutting method which can achieve both of high productivity and environmental measure, and its research and development is being continued on a global scale [(6)]. Biodegradable ester which is environment-friendly is used as cutting oil for this new system. In Japan, MQL cutting method is also called "near-dry" or "semi-dry" cutting, since it has close meaning of dry-cutting. In these years, academic-industrial cooperation has been promoting MQL method as environment-responsive cutting and eco-machining [(7) (8)].



MQL Mahining　　Existing machining (Wet machining)

Fig. 3 Comparison MQL cutting and wet cutting

This trend has been actualized as the paradigm sifting in industrial processing since UN Conference on Environment and Development (Earth summit) in 1992. In other words, it has been review the conventional cutting liquid and MQL cutting technology is expected to become common for achieving the sustainable development of metal working production.

Recently, technology mainly for machining center has been advanced for High-speed performance, complex control axes, and multi-tasking, therefore the MQL systems should be applicable to those leading edge type of machine tool.

◆Scope of application with MQL method

Here are case examples of cutting workpieces use proven MQL cutting method (Fig. 4). Aluminum is mainly used for cylinder head, cylinder block and transmission case as main automobile engine parts. Cast iron and CGI (compacted graphite iron) are used for cylinder block of diesel engine. As fast motion parts,_stored into these box parts, there are cam-shaft, crankshaft, connecting rod and input-shaft, and those materials are mainly steel. All these parts are representative parts dominating the automobile capability (or performance), and high performance of cutting accuracy is always essential for their production. For processing these parts, as appropriate rotating cutting process, drilling, reamer, tapping, boring, end-milling and milling are so. Also the MQL cutting method is put into practice use for these cutting processes. Especially, for small-diameter and deep-drilling oil hole drilling of crankshaft, since 2000, drastic replacement of wet cutting to new MQL cutting has been seen. This is because, MQL cutting was proven not only good for environment-response but high productivity, For more details of use proven cases of MQL in actual production lines, please refer to Part 4.

Recently MQL method is actively applied to other difficult work materials, titanium alloy and nickel alloy that are used much in aircraft parts and medical equipment.

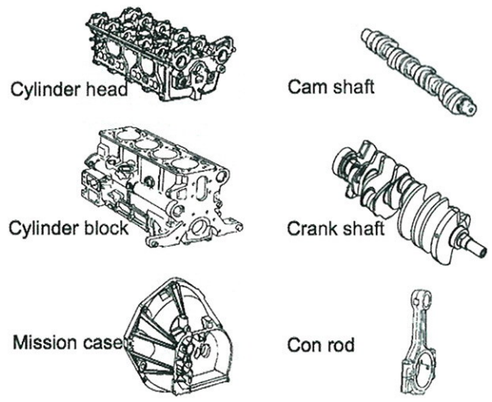


Fig. 4 Cutting work with MQL method in practice

◆Machine tool appropriated MQL

MQL machining is different from conventional wet cutting. Minimal cutting oil is provided to the machining point as oil mist by compressed air. Quantity of cutting oil used per one machining is extremely less than that of existing wet cutting. In case of general drilling for automobile part, average oil quantity per one machining is just only a drop of eye lotion. The important factor is to provide this drop of oil surely to the edge of the tool without retention. To realize this process, sophisticated technology is required. In case of wet cutting method, we can expect washing effect inside the machining area by cutting liquid. However, in case of MQL method which has less effect of such, we should consider the new alternative measure [(9)]. For putting MQL into practice in the actual production line efficiently, development of the new technology with that in mind and , and to complete the machine completed as a system. In this text, the new technology developed by Horkos, iMQL® system and MQL compatible tool holders, are introduced. For more details of peripheral technology such as chip evacuation and sensing, please refer to PART 5 (Hard wear and soft wear for system configuration).

◆iMQL® system (Patented)

iMQL® system, so called "inside spindle mixing system", is one of MQL method that cutting oil and compressed air are mixed by the mixing device located at the fore-end and inside of the spindle, providing the oil mist directly to the through oil hole of the tool. Initial letter of iMQL®, "i" means "internal mixing in spindle" and "intelligence" in our meaning. Figure 5 shows out line of such spindle system and Figure 6 shows the system configuration of the iMQL® system. With this method, since cutting oil can be fed to fore-end of the spindle in liquid form, there are several features and merits; one is that oil mist can be kept mist form, avoiding being into centrifuge separation by spindle rotation in high speed; the other is that cutting oil quantity can be controlled digitally. With this system, the machining center equipped high speed rotation of spindle and ATC (automatic tool changer) can provide proper amount of oil mist to the machining point in good response accordingly to preset amount of cutting oil for each tools. We have several award records for this system [(a, b, c, d)].

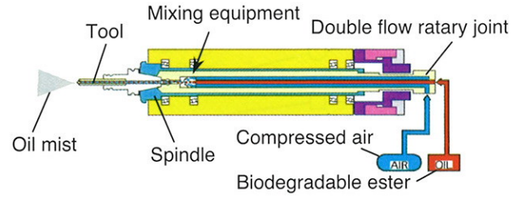


Fig. 5 Outline of iMQL® spindle equipment (Patented)

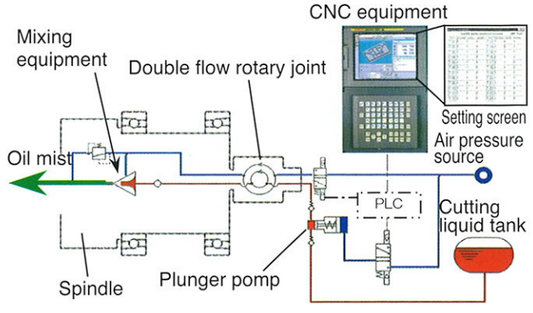


Fig.6 Structure of iMQL® system (Patented)

◆MQL responsive tool holder (Patented)

In case of MQL cutting, since cutting oil quantity is a very little, oil mist might be also influenced by the centrifugal force generated by rotation during passing inside of the tool holder. There is large room inside of the conventional tool holder (Fig. 7). If there is such room on the way of feeding route, oil mist might be inhibited in reaching the tool edge because it can be separated by the centrifugal force easily. For countermeasure, this room has been eliminated and the route that have a certain cross-section in the center of the rotation has been located (Fig.8). We, Horkos, closed license contract with tool-holders suppliers; MQL compatible tool holders can be supplied to the market by these suppliers. Here is comparison of measurement example of feeding efficiency compared between MQL compatible tool holder and conventional tool holder (Fig.9) [9].

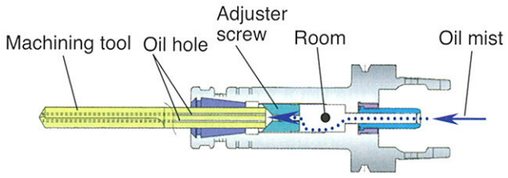


Fig.7: Conventional tool holder

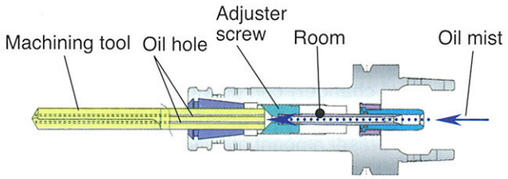


Fig.8: MQL responding tool holder (Patented)

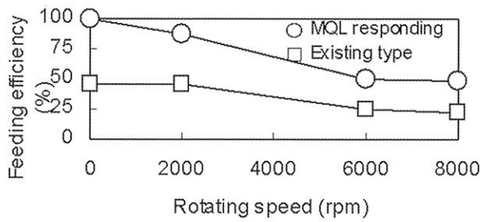


Fig.9: Comparison of feeding efficiency of oil mist [9]

◆Structure of machine responsive MQL

It is especially important for MQL to evacuate the chip from the machining area. Conventional wet cutting depends upon the flushing power of the liquid (Coolant or cutting oil liquid) for evacuating the chip from the machining area to outside. In case of conventional machine, coolant tank large quantity pooling of cutting liquid is equipped (Fig. 10). On the other hand, machine compatible with iMQL®, for reducing the cutting liquid as much as possible, the technology of chip evacuation without using cutting liquid is required. For the countermeasure, locating the through hole on the bed just below the fixture, and through that chip can be evacuated directly into the chip conveyor by its weight (Fig. 11). (In case of vertical machine, please refer to PART5.) Based on this structure, combining several kinds of MQL specific technologies, we can build up facility equipped excellent productivity and reliability. The Cutting liquid relating devices for the machine compatible with iMQL® are simple and compact. These simplicity and compactness are also highly effective to reduce the machine footprint. In this method, since there is no residual waste disposal of cutting liquid, so many merits are seen such as ; no maintenance for tank and filter, easy washing procedure and metal chip can be recycled without washing.

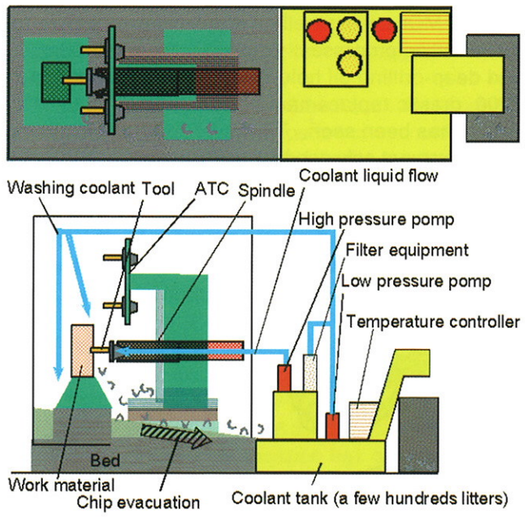


Fig.10: Structure of existing machine

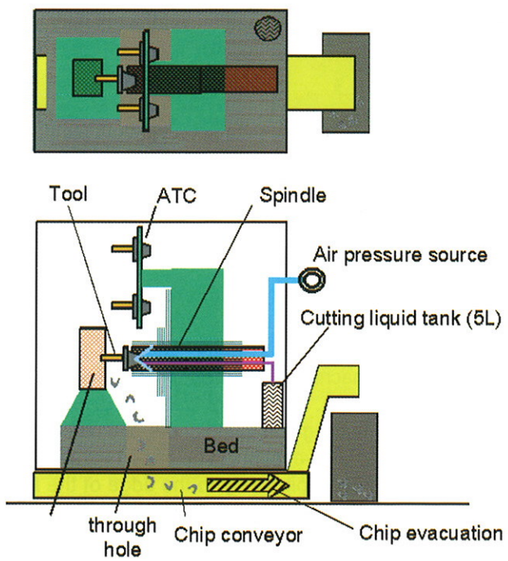


Fig.11: Structure of machine responding MQL

PART2 iMQL® Effect of energy saving

◆Consumption energy of machine tool

In response to the sharp rise in the price for energy and obligation to reduce CO2, there is no doubt for that reducing energy is quite important matter now. For machine to reduce standby power consumption has been seriously considered. There are various types of energy consumption, fixed one and variable one for the machine(Fig.1). Variable consumption means changeable one corresponding to the machine operation; spindle or feeding axis. On the other hand, fixed consumption means energy consuming none related to each machine operation; for example, compressed air for machine (mainly mist lubrication for bearing) or chip evacuation (Chip-conveyor). Compressed air is converted from consumption electricity per unit flow. High pressure coolant is classified into fixed consumption since control power (on/off) can not be frequently controlled from its nature, but should be in operation continuously. On the other hand, air for MQL is classified into variable consumption since it can be controlled on/off at comparatively high frequency in accordance with each operation.

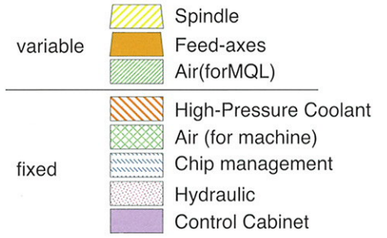


Fig.1: Variable and fixed consumption electricity for machine tool

◆Case example at production line

In this paragraph, energy consumption of machine is explained based on actual case examples. Machining specification is adduced from the case example adopted in the actual production line, that is existing wet machining was replaced to the method with iMQL® (Chart1).

Fig 2 shows power variation process graph per 1 hole of wet cutting method. It takes 10.3 sec. for 1 cycle of machining. Consumption energy is calculated by product of time and power, in other words, this would be calculated as area, which is 25.1Wh per one hole. In the conventional method, production efficiency has been improved; by increasing coolant providing pressure, and increasing the feeding speed could upgrade production efficiency. In this case, mainly operation time is reduced and therefore graph will be shortened towards the arrow 1 and fixed consumption would be shortened because machining time might be shorter. However, electricity consumption of coolant pump have to be increased for the requirement of higher-pressure, the energy saving in total can not be expected.

◆Energy saving efficiency of iMQL®

On the other hand, in case of iMQL®, machining speed is improved 3 times as fast as the case of conventional way, since chip evacuation efficiency from machining hole has been improved. Fig 3 shows power in temporal variation of iMQL® machining. In case iMQL® machining, 3 direction of energy reduction are seen, (arrow 1) fixed consumption can be decreased because of shortage of machining time, (arrow 2) electricity can be reduced without using coolant pump. Therefore, (arrow 3) synergy can achieve drastic energy saving. Total consumption energy is only 9.9Wh per 1 hole, never the less that variable energy increases. It means, this case study shows iMQL® can achieve in reduction of 61% in energy against wet machining.

Chart 1: Case example of machining specs at actual production line

Item	Wet machining	iMQL® machining
Cutting liquid	Soluble emulsion 2MPa	Biodegradable ester 120m/h
Work material	Aluminum cylinder block	
Machining	Φ6.0mm, depth 78 mm, Drill machining (stop hole)	
Rotating speed	5305 rpm	7958 rpm
Feeding speed	637mm/min.	1910mm/min.
Machining time	7.3 sec./hole	2.5 sec./hole
Feeding time	3.0 sec./hole	
Machine	RM70H (HORKOS), Spindle: HSK63A	

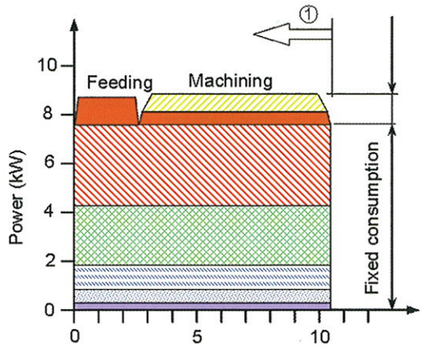


Fig. 2: Consumption energy in wet machining

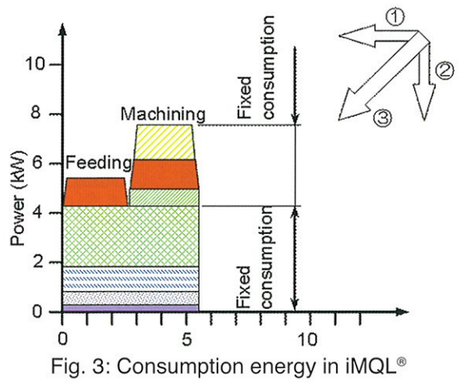


Fig. 3: Consumption energy in iMQL®

PART3 Machining mechanism of iMQL®

◆Lubricating efficiency of ester

According to Dr. Yokota of NISSEKI MITSUBISHI CORP report (10) "Coefficient of friction by MQL is lower than that by soluble cutting liquid (wet machining) or dry machining, which means MQL works for lubrication even though its quantity is infinitesimal". It indicates the capability of MQL in reduction of friction between tools and work material. As like as MQL, as the case of the action when infinitesimal fat acid ester behaves to cutting chip / interface of the tool, there are two cases, one is that fat acid ester sticks physically, another is that fat acid or alcohol sticks physically and chemically. One of the factors, as the reason why hydrogen is generated, it seems that metal soap would be generated due to chemical absorption of fat acid as Figure 1 shows. Metal soap generated on the face of metal behaves the effect to reduce the friction if the temperature is under hundred and several tens degree centigrade [1]. When chemical reaction like this is generated at the machining point or the surface of chip continuously and stably, effective result like reducing machining friction or better chip evacuation can be expected.

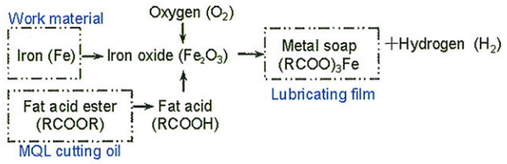


Fig. 1: Fat acid behavior under the oxygen (model) (10)

◆Tool abrasion control effect

Figure 2 shows the result how tool life differs depending on methods of cutting oil providing systems. This is the experiment of drilling in continuous machining of the steel [9]. Each condition of cutting oil solution providing methods are; 1: Entirely dry, 2: iMQL® Q'ty 5ml/h, 3: iMQL® 10ml/h, 4: Wet machining with external nozzle and 5: Wet machining 2MPa provided through the spindle. Other conditions are common. Tool life shows total length of machining hole up until to continuous machining is possible.

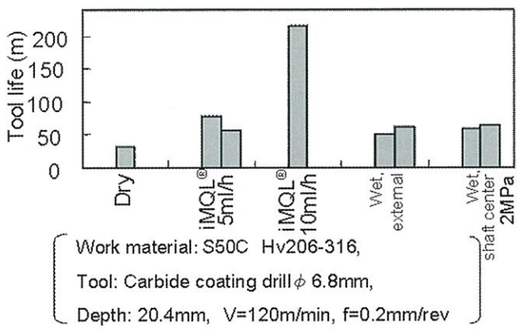


Fig. 2: Correlation chart cutting solution providing method and tool life [9]

In case of dry machining, the reason for its short tool life would be excessive sharp rise in temperature of tool edge. With what kind of reason does it differ between iMQL® machining and wet machining? In fact, this is because that mechanism of tool edge wearing differs significantly between in case of iMQL® and in case of wet machining. Fig 3 shows the drill edge condition after 60m machining. According to this figure, in case of wet machining, there are numerous cracks likely generated by thermal impulse at the external corner (a). And there are adhesions of work material near at the center of drill (b) where rotation speed is relatively low. There are cratered damages (c) possibly caused by abrasion of adhesions on the edge. On the other hand, in case of iMQL® 10ml/h, there is no cracks, nor frictions (d) (e), and cutting edge can maintain good condition as same as new tool. In case of iMQL® method, by keeping supply with appropriate quantity of lubrication to tool edge, thermal impact on the circumference of tool can be absorbed, and also adhesion of work material can be minimized. This synergy works effectively for tool abrasion control, which wet machining has never achieved.

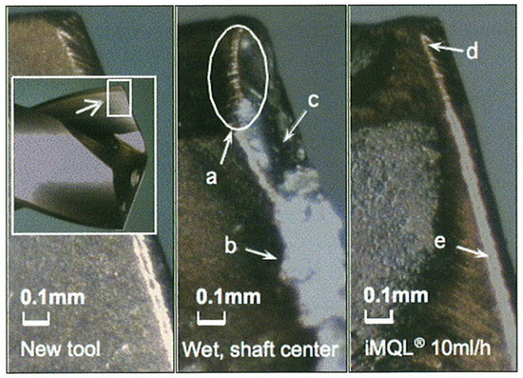


Fig. 3: Tool edge condition after machining 60m

◆Tool vibration control effect

In case machining with high speed rotation of spindle, like as finish boring of aluminum material, it is especially important to improve the tool balance of axial runout and to control its vibration. In case of wet machining, it tends to lose tool weight balance, because there is coolant liquid inside tool or tool holder unstable. It is possibly that tool vibrates unsteadily because of inner flow of high pressure coolant and the influence of air bubble generating and disappearing (cavitations) inside flow route. These influences will affect machining inaccuracy.

On the other hand, in case of iMQL®, since quantity of oil lubricant is infinitesimal and also minimal compressed air convey oil lubricant, negative influence is extremely small. By these reasons, it is expected that iMQL® is able to improve machining accuracy.

PART4 iMQL® records at actual production line

Effort in putting MQL into practical use for technological improvement is recent trend all over the field of metal working. Especially in the automotive industry, a number of verification examples have been reported at several companies. We introduce case examples of some these companies using our original technology, "iMQL® system", in their issued reports.

◆Case example of Toyota Motor Corporation [11]

According to Japanese industry journal, "Machine and Tool" in the July 2003 issue [11], It was reported that Toyota was promoting to produce earth-friendly products for responding to global environmental protection, that was to establish eco-friendly process at any stage of production such as development, production and disposal. From the perspective of global environmental protection requirement and enhancement of cost competitiveness, dry machining or semi-dry machining is deemed a very important subject, it says. In this article, a case example is also reported, as subject "semi-dry machining – drilling oil hole of aluminum" that semi-dry machining of internal spindle providing method was applied to the machining of aluminum cylinder block small deep hole. In case of aluminum small deep hole machining, to prevent tool from adhesion of chip, discharge rate of oil should be increased, therefore inside spindle mixing system is adopted, which saves length from the point of mixing equipment (mist flash equipment) to edge of tools. The machine used was the horizontal machining center, RM70H made by Horkos Corp, and iMQL® system was applied as MQL equipment. As the result, in the report, stable cutting condition was able to be upgraded in 3 times efficient(V=150m/min., f=0.24mm/rev) as that of conventional wet machining(V=150m/min., f=0.12mm/rev). Fig 1 shows correlation between machine efficiency and oil discharge rate [11]. Less than 0.1ml/hole of oil discharge rate were used for each machining.

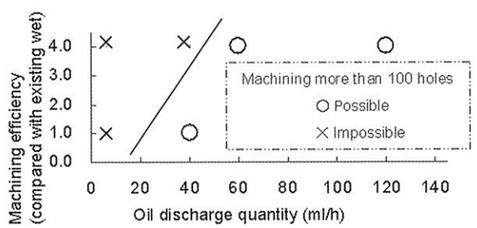


Fig. 1: Correlation between machine efficiency and oil discharge rate [11]

◆Case example of Mazda Motor Corporation [3]

Mazda has applied the semi-dry machining system for all of machining process in the aluminum cylinder block line which had been introduced into mass-production since June 2002[3]. As the result, Mazda was given the highest award named "Award of minister of economy, trade and industry", in energy saving of the nationwide contest organized by the Energy Conservation Center, Japan in 2002. Mazda has defined machining semi-dry system alternate solution which can minimize energy consumption, natural resource and cost, and can verify the product quality and operation without coolant system; this has been in their own report[3]. Mazda achieved cutdown the amount of coolant and electricity drastically (Fig. 4, 5) with using semi-dry machining system thoroughly, once they breakdown the factor of energy consumption in existing coolant machining line (Fig. 2) and quantity of thermal waste disposal (Fig. 3).

In this production equipment, 3 lines of Horkos transfer machines are adopted and installed. These equipments are automatic machining system, which process is after throwing work material into machining area, milling, drilling, reaming, rough boring and deep hole drilling as integrated system. For difficult process such as reaming or deep hole drilling, iMQL® system has been introduced proactively. For improvement of energy saving, "Eco flushing system (PAT.)" by Horkos is adopted thoroughly.

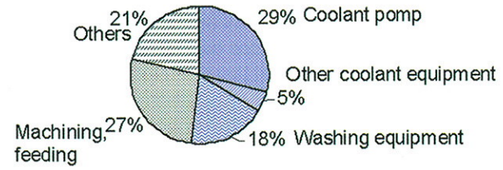


Fig. 2: configuration items of consumption electricity at machining line (existing case) [3]

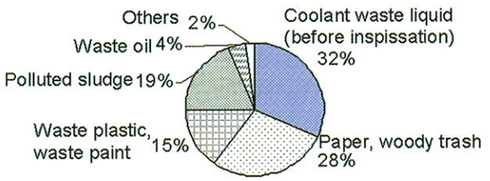


Fig. 3: Disposal waste brought into incinerator plant (actual case) [3]

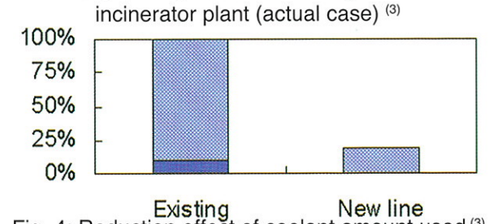


Fig. 4: Reduction effect of coolant amount used [3]

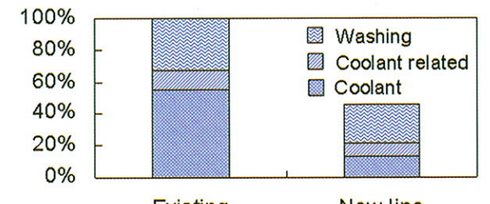


Fig. 5: Reduction effect of electricity used [3]

◆Case example of Japanese major parts manufacturer [12]

This example is reported in the Japanese industry journal, "Machinery lubrication 2008" vol. 4. In this journal, a case of automotive parts production line with max capacity 25000parts/month is reported as good example. This company adopts Horkos space saving machining center "NS70" with "iMQL®" system for aluminum transmission case machining and achieve epoch-making iMQL® production system for actual production. This system has been achieved through close relationship between machine-user and Horkos. Originally the project started merely from the development of footprint saving type of the machining center (machining unit). After accomplishment of the space saving machining center, iMQL® system is adopted thoroughly to all production processes in 2007, and compact and high efficient production line has been realized. Recently this kind of concept (combined with iMQL®) is the mainstream of this company, and no coolant has not been used since that time. (Fig. 6 (12)). As you can see, with combination of MQL-responsive machining center and iMQL® system, successful examples for large scale of production line for aluminum machining process ,which had been taken as difficult to adopt MQL, have been built up in many practical metal workshops.

Fig. 6: Mission case machining line thoroughly with iMQL® [12] (NS70 as machining unit.)

◆Case example of NCMS (US) [13]

This is a case example [13] of NCMS (National Center for Manufacturing Sciences of United States), who tried in the collaborative research "Basic research on Near-dry machining" together with HORKOS from the year of 2000 to 2003. The aim of this research is to evaluate these several conditions on the actual machine; such as case 1: machining with iMQL®, case 2: with iMQL and iMQLV (chip evacuation, c.f. P10), and case 3: wet machining (wet, coolant-through method). Horkos horizontal rapid machining center, HFN-P40H with HSK63A, and iMQL® system were adopted for this experiment (Fig. 7). With the each condition, 10000 pieces of work material (Aluminum cast Engine bracket) were machined and results were evaluated in various perspectives. Chart 1 shows the conclusion of this project. Machining with iMQL® (case 1) is the most reasonable in machining cost. Machining® with iMQL & MQLV(case 2) is the best condition in down time and airborne mist. According to Chart 2, wet machining (case 3) needs more personnel cost on cutting liquid handling. The feature of iMQL® compared with wet machining are, (1) 9% reduction of machining cost, (2) 67% reduction of airborne mist, (3) 56% reduction of energy consumption and (4) realization of easy chip recycle, in short, these results bear out that iMQL® system has so many advantages in the actual workshop. Also, it is quite interesting aspect that even though compressed air is used during process of MQL machining, its consumption is almost same as the case of wet machining.

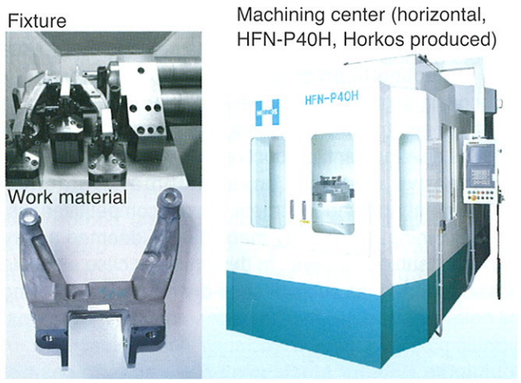


Fig. 7: Adopting machine for NCMS project

Chart 1: Result of comparing test at NCMS[13]

*MQLV:It means MQL machining + Chip evacuation equipment (Vacuum).

Item	MQL	MQLV *	WET
Num of machining work material	10,000 pieces	10,000 pieces	10,000 pieces
Machining cost	$ 5.000	$ 5.385	$ 5.477
Cycle time	149 sec.	155 sec.	149 sec.
Down time	2 hours	0 hour	4 hours
Floating mist	0.062 mg/m³	0.040 mg/m³	0.186 mg/m³

Chart 2: Breakout of machining cost per 1 work material [13]

No	Item	MQL	MQLV	WET
1	Machining center cost	$ 0.420	$ 0.462	$ 0.425
2	Personnel cost (machine operation)	$ 4.139	$ 4.305	$ 4.139
3	Tooling	$ 0.313	$ 0.488	$ 0.313
4	Electricity	$ 0.019	$ 0.019	$ 0.043
5	Air	$ 0.025	$ 0.026	$ 0.024
6	Cutting liquid	$ 0.006	$ 0.006	$ 0.022
7	Personnel cost (Cutting liquid related)	$ 0.084	$ 0.084	$ 0.481
8	Liquid waste disposal	$ 0.000	$ 0.000	$ 0.030
9	Chip recycle	- $ 0.005	- $ 0.005	$ 0.000
	Total	$ 5.000	$ 5.385	$ 5.477

PART5 Hard wear and Soft wear for system configuration

◆Gravitational Direct chip evacuation

For MQL-responsive machining center, it is required to minimize use of any liquid flush for chip evacuation as small as possible. To enable iMQL® system to maximize its potential efficiency, Horkos has developed various structures in regard to chip evacuation and turned such technology into the products (machining centers). Here we take example to show the structure outline of horizontal machining center RM70H(Fig.1) and multi-spindle special purpose machine(Fig.2). MQL-responsive machining center (Fig.1) has through hole at the base of machine below the marching area. Through this hole, chips drop down directly into the chip conveyor by gravitational force. This is standard spec for machining centers of HORKOS. Thanks to this system, chip evacuation from the machine can be easier, that leads simplification of coolant flush for chip evacuation. Additionally, thermal influence can be reduced since heated chips rarely are accumulated on the machine base. "Ram-feed" structure is adopted for Z-axis sliding unit with embedded structure into the fixed column. Also, as XY-axes cover simplified steel plate (HORKOS original) is used. Thanks to this structure mechanical area is perfectly isolated from machining area preventing affect of entry of chip and liquid.

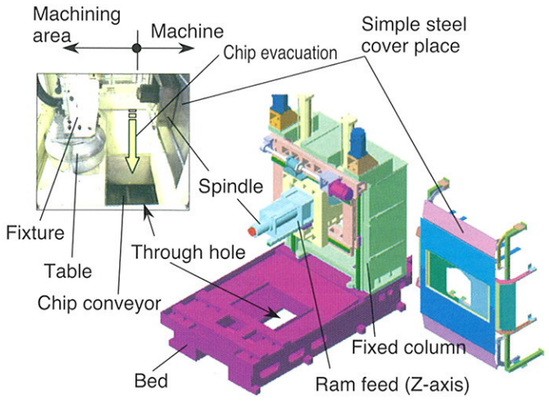


Fig.1 Structure of MQL-responsive machining center

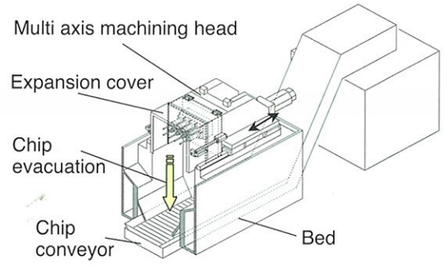


Fig.2: Structure of MQL-responsive multi-spindle machine (PAT.)

In case of MQL-responsive multi-spindle special purpose machine (Fig.2, PAT.), machining head can be set in the bed of machine. Furthermore when movable cover is attached on the outer multi-spindle head, chip evacuation can be much more ensured.

◆Simple steel cover plate equipment

Recent years, machine tool has steadily become with higher speed performance, therefore performance of movable cover has gained much more importance same as other machine elements. Especially for the automated equipment, reliability and high durability are prioritized to the other elements. And the requirement has been getting more demanding year by year. Ready-made covers such as, telescopic cover, accordion cover and take-up cover are no longer capable to meet the requirement from the above mentioned grounds. Considering such trends, Horkos has developed "simple steel plate cover equipment (Fig.3)" in 1999, which have been applied mainly to the machining centers as standard. The structure of this cover is like folded steel plate, designed to be enclosed in side area of main body moving along specially designed rail. This is simple structure and cover can catch chip or coolant surely at the face of steel plate. It realizes high reliability and high durability.

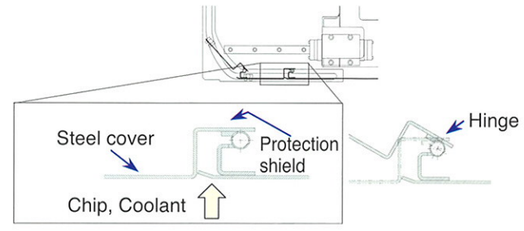


Fig. 3: Simple steel cover plate equipment (PAT.)

◆Bed-less structure (PAT.)

Chip evacuation efficiency is improved dramatically with no base (bed) structure downward of fixture. In this paragraph, we introduce you machining center "N series", which was developed and designed based on new concept "bed-less" (base-less). Fig 4 shows the outline of bed-less structure. Appearance is cube, front mounted fixture is equipped, and machining unit is located at the upper part. Auto tool changer (ATC) is housed in the base, and work material is fixed with being hanged at the front of the base as Figure shows. Boxy cover is equipped as surrounding the fixture mounted on the front of the base, and machining area becomes enclosed area. For Z-axis, ram-feed structure is given. These structures enable chip to be evacuated out from the machine without touching any structure of machine. In addition, mounting fixture on the front of the base, shorter length of force transmission route from the spindle to work material is expected than the on-bed equipped type, that is, high rigidity for small machine body is available.

Fig 5 shows the case example of that B-axis table is mounted on the machining center "NJ50" made by Horkos. "N series" which involves NS70 and NJ50 have feature that all equipments and maintenance parts are intensively located at front and rear of the machine. This means no maintenance is required from both machine sides. Electrical cabinet is movable for improving maintenance performance. These contraptions enable the machine to be installed with minimum "machine to machine" pitch, as you can see, together with high efficiency of iMQL® (reduction in number of machine because of its high efficiency), it can achieve drastic reduction in footprint of total equipment.

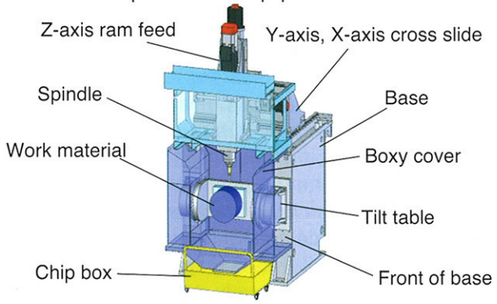


Fig. 4: Bed-less structure (PAT.)

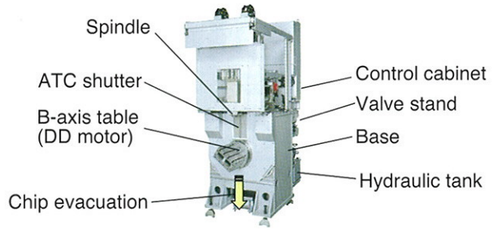


Fig. 5: Case example of NJ50

Bed-less machining center, with its distinctive structure, has possibility to have various configurations of fixtures that have never existed before. Fig 6 shows variation in configuration of fixture as examples of N series machining center. Case (b) shows that chip trash box can be placed directly below of the fixture. Case (c) shows that it can realize downsizing machining center for end face machining of the long size work material, this is one of the big advantages of this type of structure.

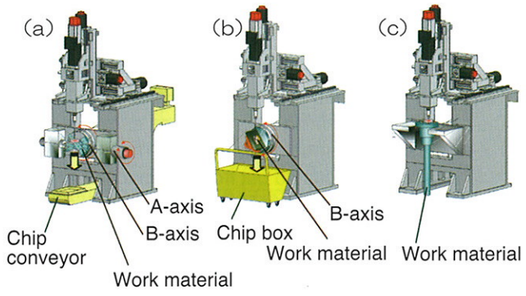


Fig. 6: Varied fixtures of N series machining center

◆Eco flushing system (PAT.)

In case of machining process which generates many chips during machining such as cast iron or aluminum, it sometimes needs to use liquid flush for chip evacuation. In this case, to balance both environmental and energy saving requirement, there is way that only appropriate (minimum) quantity of washing liquid flush is used intermittently. However, the conventional method requires driving the coolant pump constantly, since cutting liquid have to be stored in coolant tank, circulate and flushed through long pipe (Fig.7). Under such condition, it is impossible to flow the washing liquid intermittently according to the operating condition and chip bank condition. Consequently, Horkos has developed the "Eco Flushing System" as in the following Fig.8 and Fig.9. This system is that washing liquid is stored in the sub tank (40L) once, and flown when it is necessary. With this system, intermittent flow timely to operation condition and arbitrary maximum instant flow can be realized. Since washing liquid is supplied moderately in average flow from the tank to sub tank, pipe resistance (pressure loss) is small ,and therefore pump discharge pressure can be reduced to the degree equivalent to the height of washing liquid (H). This synergetic effect make it possible to downsize the motor pump and energy saving. Out put power of the pomp (W) is proportional product of liquid pressure (P) and flow (Q). Therefore, compared with conventional system, when 1/2 of the pressure and 1/5 of average flow realized by intermittent operation, 1/10 energy consumption is surely expected.

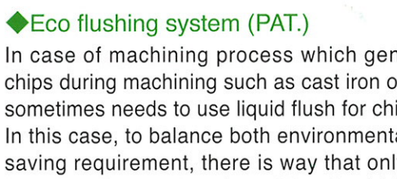


Fig. 7: Existing coolant providing system

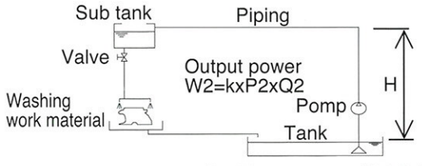


Fig. 8: Eco flushing system (PAT.)

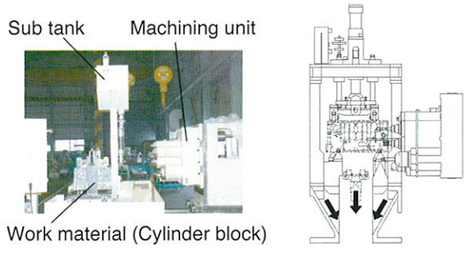


Fig. 9: Case example adopted Eco flushing system

◆Vertical counterturn fixture

Thanks to the mechanism with the motion of vertical counterturn (Fig.10), this type of fixture can prevent chips from accumulating onto the fixture and can reduce the machine trouble by such accumulation of chips. This structure has been applied to the machining center "HFN-P40H" made by Horkos ,and we have already delivered this type of machine to the actual production lines.

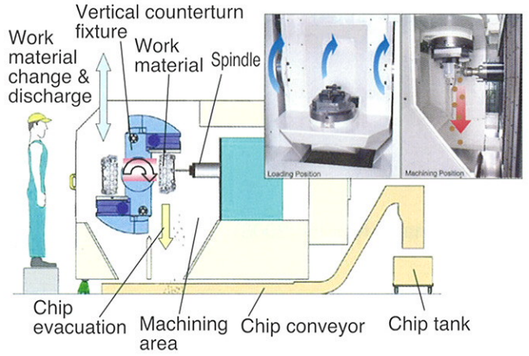


Fig. 10: Structure of vertical counterturn fixture

◆Chip evacuation system

Chip evacuation system is clean-up system by vacuuming chip directly from area close to the machining point and taking them to outside of the machine by the negative pressure (Vacuum). Chip evacuating drilling tool holder (fig 11) has special feature that keeps the certain distance between surface of the work material and its hood automatically keeps distance to workpiece surface with the balance between its negative pressure inside of holder and atmosphere pressure (PAT.). Thanks to this mechanism, it can prevent the hood from touching surface of work material. This is an effective chip evacuation system for the case which needs to remove chips from inside of the work material, or needs to prevent chips scattering as like CFRP machining. Here are the case examples of actual production line (Fig.12) and vacuuming equipment, DVC (Fig.13) equipped with auto discharge function.

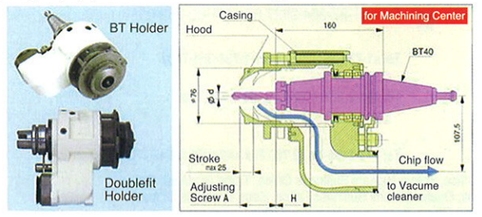


Fig. 11: Chip vacuuming holder for drilling hole (PAT.)

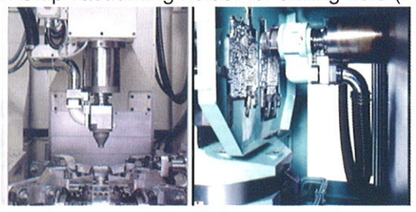


Fig. 12: Case example of chip vacuuming system

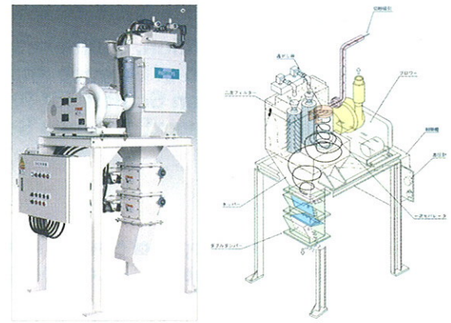


Fig. 13: Special vacuuming up equipment (DVC)

◆Operation panel screen of iMQL®

For iMQL® system, as its distinctive feature, can control discharge amount of cutting liquid arbitrarily. To use its technological performance, iMQL®-responsive machining center, HORKOS made, has function to set discharge amount accordingly to detail condition by each tools. Fig 14 shows the example of operation panel setting screen of cutting liquid quantity. This is simple system which is enough to put the supply quantity (ml/h) with numerical key into each input box of each tools on the screen. In addition, real time auto diagnosis system is prepared as option.

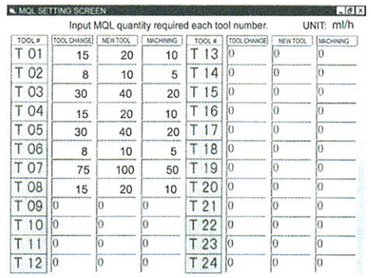


Fig. 14: Example of setting iMQL® operation panel screen

◆Spindle torque detective Tool breakage preventing system (PAT.)

Deep hole machining process has the possibility of tool breakage risk by sudden chip-choking. iMQL®-responsive machining center, has function to monitor the rotary torque of spindle motor (direct) during machining in a real time (Fig.15) for prevent tools from breaking . There are many of practical accomplishment in crankshaft oil at actual production lines.

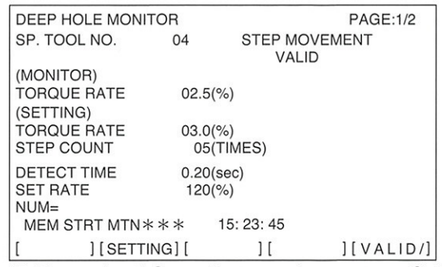


Fig. 15:Example of Operation panel screen on Spindle torque detective Tool breakage preventing system