특 별 강 연

21세기의 공작기계 기술

姜 哲 熙
선문대학교 교수

21세기의 공작기계기술

1. 공작기계공업의 현주소

◆세계주요국의 공작기계생산 무역액

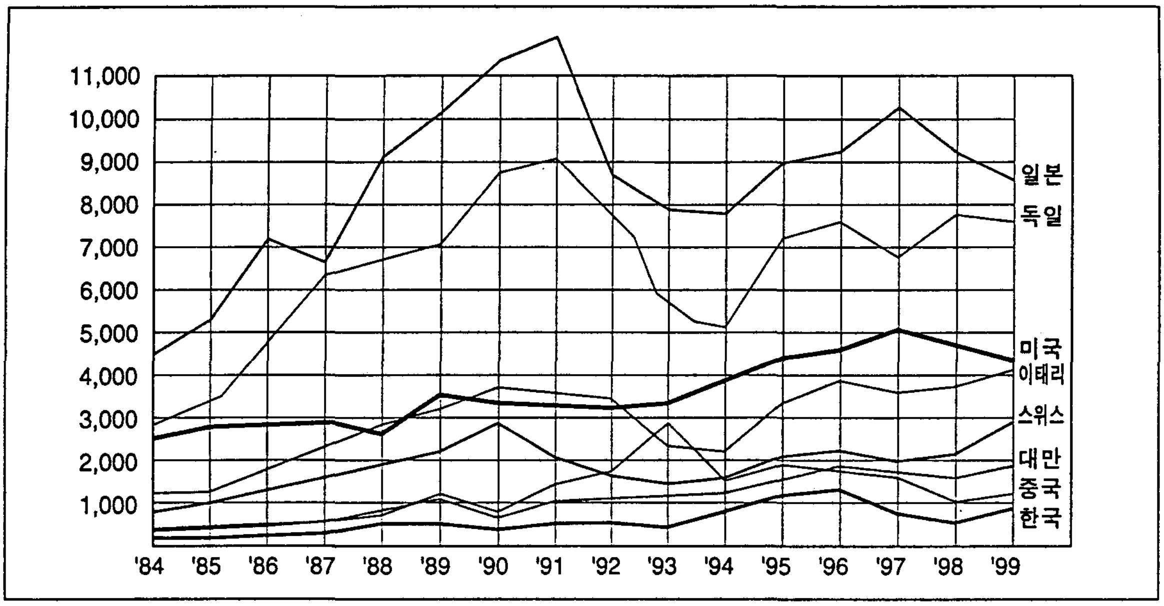
(단위 : 백만불)

연 도	1999(잠정치)					1998(수정치)				
	생 산 액			무 역 액		생 산 액			무 역 액	
	합 계	금속절삭기계	금속성형기계	수 출	수 입	합 계	금속절삭기계	금속성형기계	수 출	수 입
일 본	7,722.7	6,564.3	1,158.4	5,528.7	662.6	8,980.4	7,723.1	1,257.3	5,917.3	632.4
독 일	7,481.4	5,162.2	2,319.2	4,133.1	2,520.8	7,582.0	5,307.4	2,274.6	4,357.0	2,351.0
미 국	4,348.7	3,087.6	1,261.1	1,303.7	4,063.4	5,390.7	4,043.0	1,347.7	1,484.2	4,762.7
이 태 리	3,763.6	2,220.5	1,543.1	2,083.1	1,390.8	3,647.0	2,188.2	1,458.8	2,151.2	1,300.0
스 위 스	2,033.0	1,667.1	365.9	1,808.3	391.9	2,106.6	1,727.4	379.2	1,837.3	422.5
대 만	1,675.2	1,256.4	418.8	1,261.8	753.6	1,589.0	1,191.8	397.3	1,170.6	714.8
중 국	1,087.2	848.0	239.2	269.0	1,432.9	1,029.6	792.8	236.8	250.0	1,390.6
스 페 인	969.0	668.6	300.4	534.4	530.6	944.8	651.9	292.9	531.2	445.3
영 국	952.5	752.5	200.0	808.5	800.5	1,122.2	886.5	235.7	891.2	1,156.2
프 랑 스	800.9	520.6	280.3	582.5	1,355.7	788.1	512.3	275.8	571.7	1,259.0
한 국	706.4	635.8	70.6	372.0	665.0	487.4	453.3	34.1	357.0	443.5
캐 나 다	515.5	309.3	206.2	276.9	848.3	425.3	255.2	170.1	262.9	868.9
브 라 질	364.6	295.3	69.3	99.3	370.9	570.6	462.2	108.4	155.5	580.5
체 코	283.3	260.6	22.7	254.5	214.1	308.4	283.7	24.7	276.9	233.0
벨 기 에	256.7	28.2	228.5	450.5	411.1	273.6	54.7	218.9	511.2	510.0
터 어 키	213.3	46.9	166.4	60.3	190.0	250.8	65.2	185.6	52.9	326.0
오 스 트 리 아	211.4	112.0	99.4	315.1	275.6	208.1	110.3	97.8	186.8	284.8
스 웨 덴	206.1	90.7	115.4	174.2	408.0	210.1	92.4	117.7	181.2	404.1
핀 란 드	168.3	23.6	144.7	144.8	101.2	170.6	22.2	148.4	138.7	149.7
인 도	162.6	139.8	22.8	11.6	162.6	162.0	140.9	21.1	14.7	254.5
네 덜 란 드	134.2	25.5	108.7	176.8	410.0	144.4	27.4	117.0	187.6	433.0
러 시 아	110.5	78.5	32.0	68.0	150.0	117.2	76.2	41.0	75.7	179.5
슬 로 바 키 아	79.4	72.3	7.1	58.4	80.8	90.5	83.3	7.2	60.2	99.9
덴 마 크	57.5	17.8	39.7	70.0	163.7	57.5	17.8	39.7	70.3	164.0
포 르 투 갈	41.5	5.4	36.1	25.6	120.3	43.4	5.6	37.8	26.7	125.7
루 마 니 아	38.8	27.5	11.3	43.5	49.7	51.9	36.3	15.6	49.5	57.9
유고슬라비아	33.8	27.0	6.8	21.9	6.6	51.3	41.6	9.7	40.4	11.0
크 로 아 티 아	28.0	28.0	0.0	20.0	20.0	39.3	38.1	1.2	35.2	20.6
아 르 헨 티 나	15.7	11.0	4.7	10.8	74.9	24.1	16.9	7.2	9.1	126.9
남아프리카공화국	7.5	0.5	7.0	2.0	36.0	7.5	0.5	7.0	2.0	40.0
멕 시 코	6.7	4.0	2.7	4.0	67.3	10.5	6.3	4.2	4.5	105.5
합 계	34,476.0	24,987.6	9,488.4	20,973.3	18,728.9	36,884.9	27,314.6	9,570.3	21,860.7	19,853.5

※ 한국 '98 수출액은 중고기계가 제외된 금액임.

◆세계주요국의 공작기계생산액추이('84~'99)

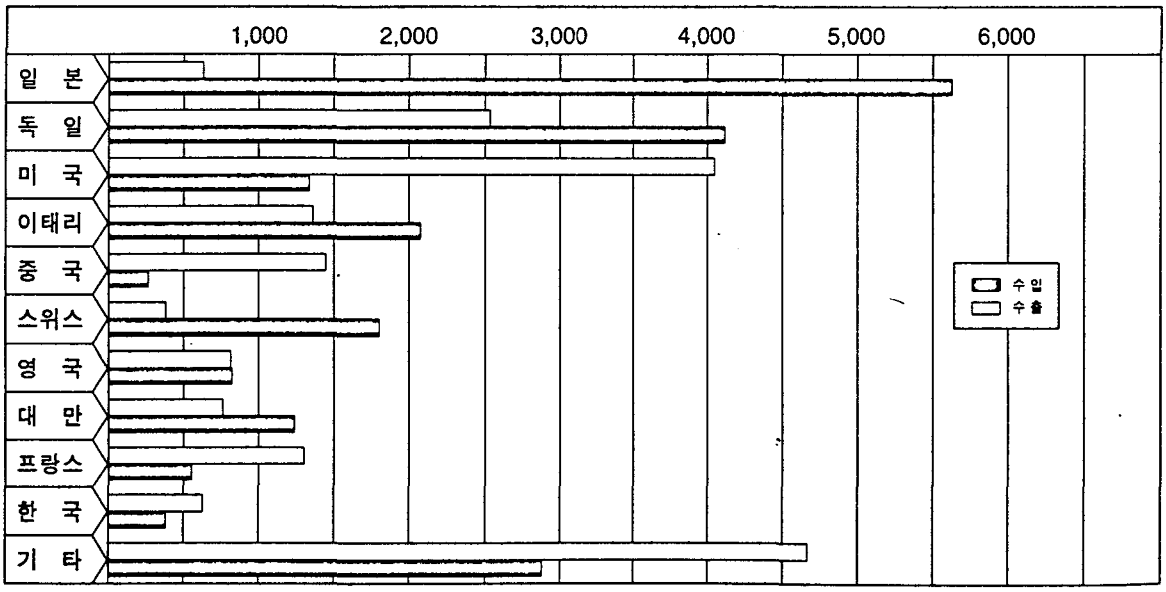
(단위 : 백만불)



자료 : Gardener publication, INC. (Metalworking Insiders' Report誌)

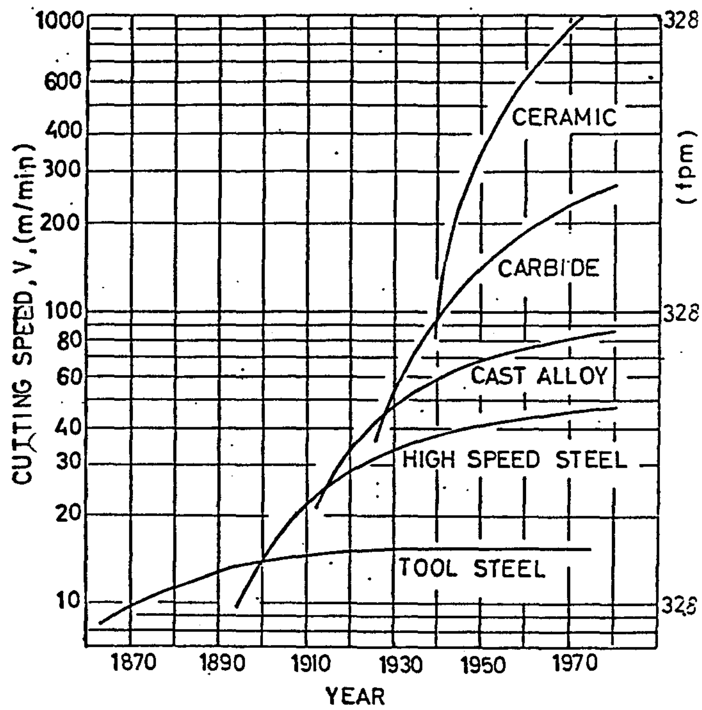
◆세계주요국의 공작기계무역액('99)

(단위 : 백만불)



자료 : Gardener publication, INC. (Metalworking Insiders' Report誌)

2.공구재료의 발달과 공작기계



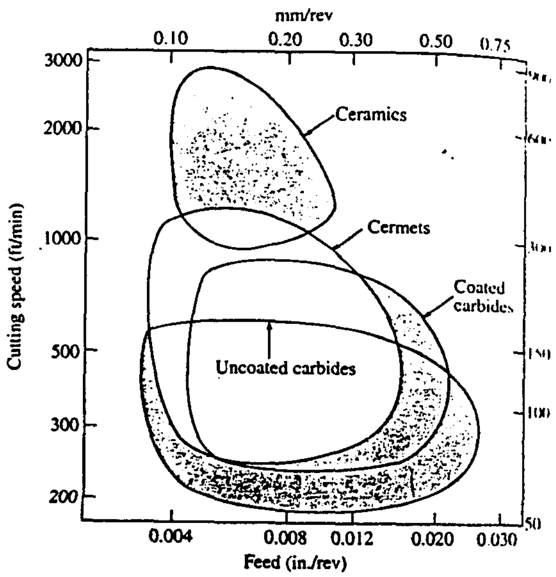
◆ CBN Tool

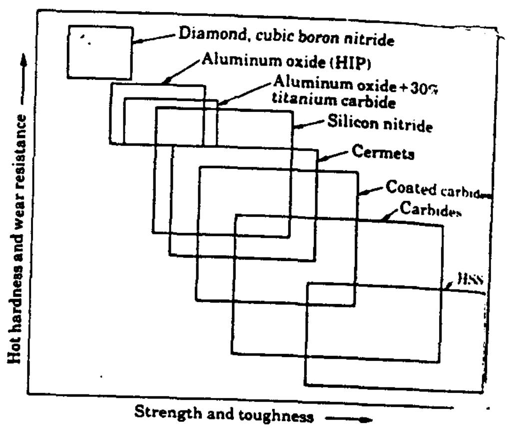
CBN(Cubic Boron Nitride)

1972 GE에서 개발

1977 Sumitomo도입

1) Diamond 다음 가는 경도
2) 열전도성이 높다.
3) 철제금속과 반응이 적다.
4) 대열성이 높다
5) 비삭재와 고착이 적다
6) 가공변질층이 발생

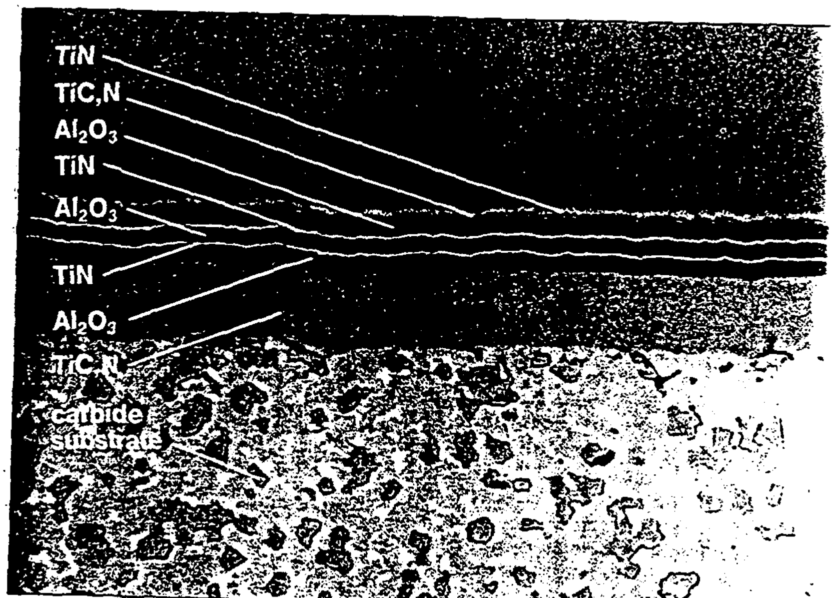




Multiphase coatings. The desirable properties of the coatings just described can be combined and optimized with the use of multiphase coatings. Carbide tools are now available with two or three layers of such coatings and are particularly effective in machining cast irons and steels.

The first layer over the substrate is TiC, followed by Al_2O_3, and then TiN. The first layer should bond well with the substrate; the outer layer should resist wear and have low thermal conductivity; the intermediate layer should bond well and be compatible with both layers. Typical applications of multiple-coated tools are:

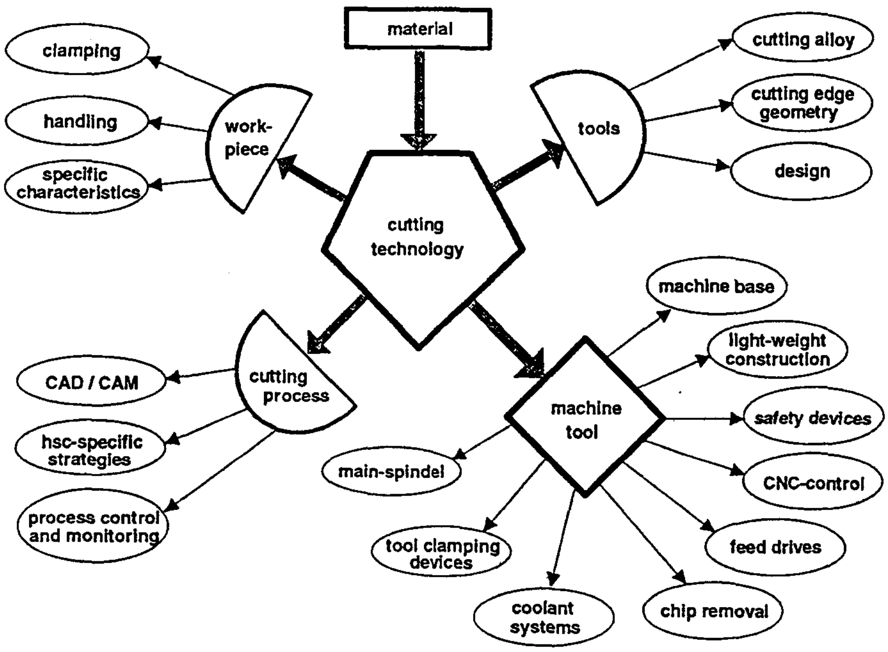
a) High-speed, continuous cutting: TiC/Al_2O_3.
b) Heavy-duty, continuous cutting: TiC/Al_2O_3/TiN.
c) Light, interrupted cutting: TiC/TiC + TiN/TiN.



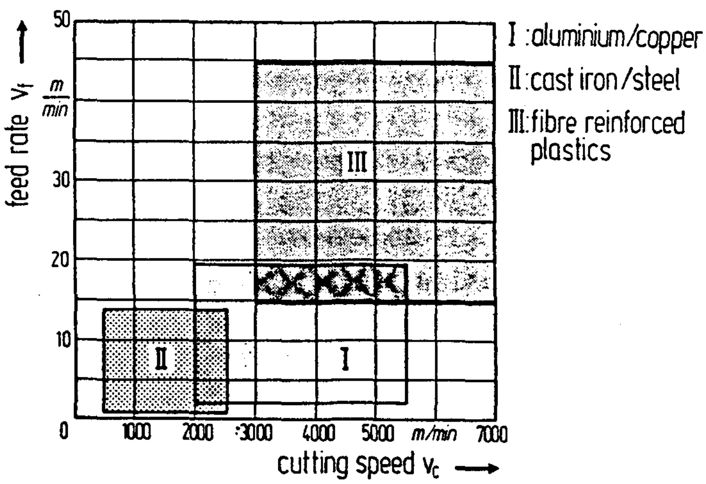
1. Multilayer coating architecture of Kennametal's KC990 grade: a TiCN backing layer 6 μm thick, an active zone 3 μm thick of three alternating Al_2O_3 layers separated by very thin TiN layers, and a finish layer 1 μm thick made up of a flashing of TiCN topped by TiN. The tungsten carbide alloy substrate contains about 6% cobalt and 7% cubic carbides, for a balance of toughness and hardness.

3.공작기계의 고속화 기술

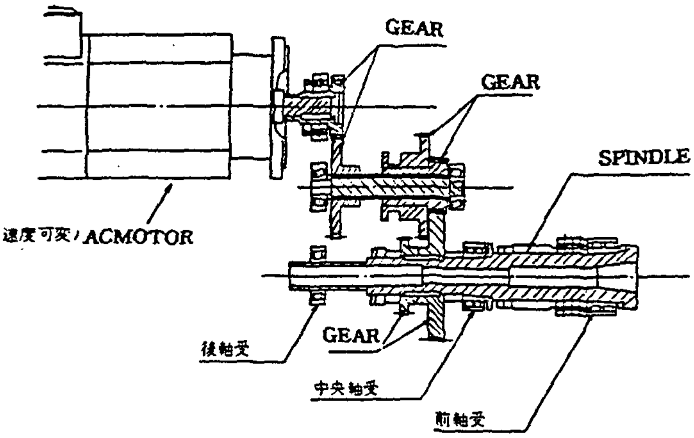
3-1 스핀들의 고속화



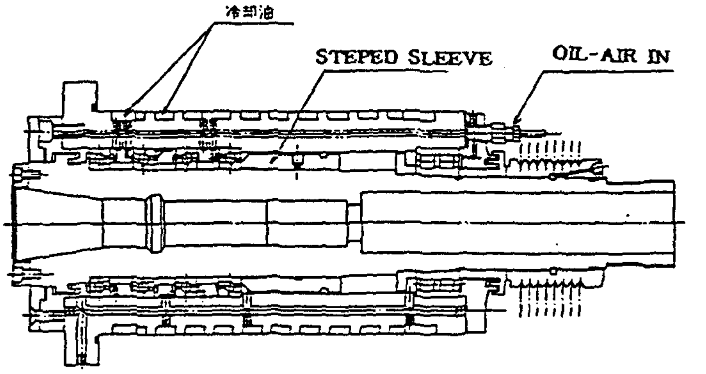
Influence of cutting technology



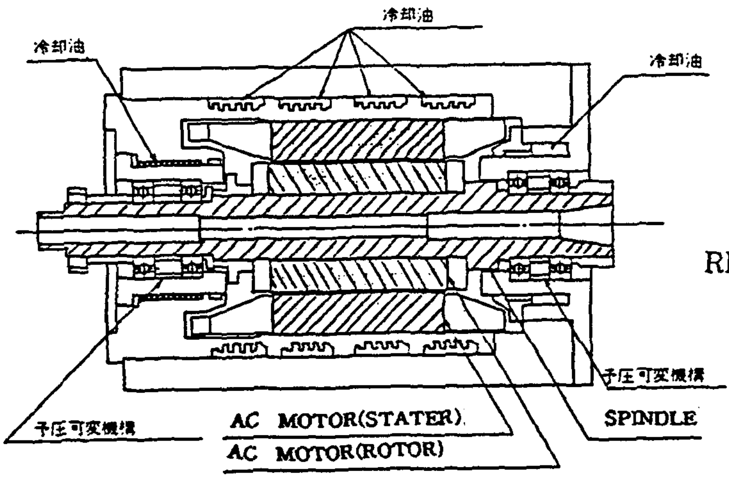
Optimum technology application ranges for high speed cutting



RPM 5,000 dn=50×10^4

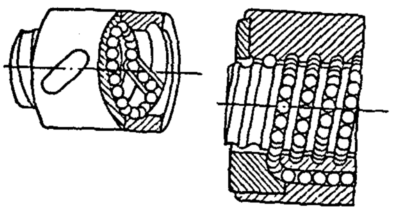


RPM 12,000 dn=78×10^4



RPM 25,000 dn=112.5×10^4

3-2 이 속속도의 고속화



Ball-bearing screw and nut

(1) MC의 이송속도의 현재

Lead 10 ~ 14㎜의 Ball Screw 2000 RPM의 Servomotor 사용.

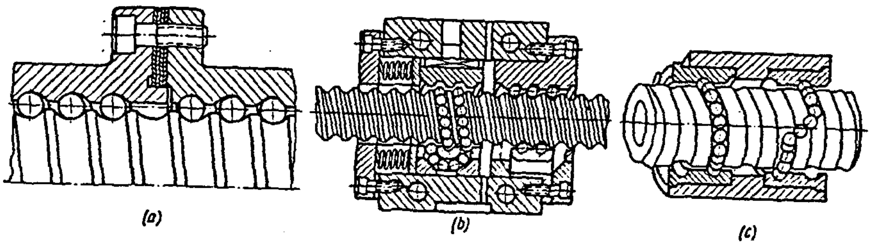
이송속도 : 20~30m/min 0.2~0.3G

(2) 고속이송속도

Lead 20㎜의 2조 Screw사용

3000 RPM의 저강성 속도 Servomotor 사용

이송속도 : 60m/min 1.0G



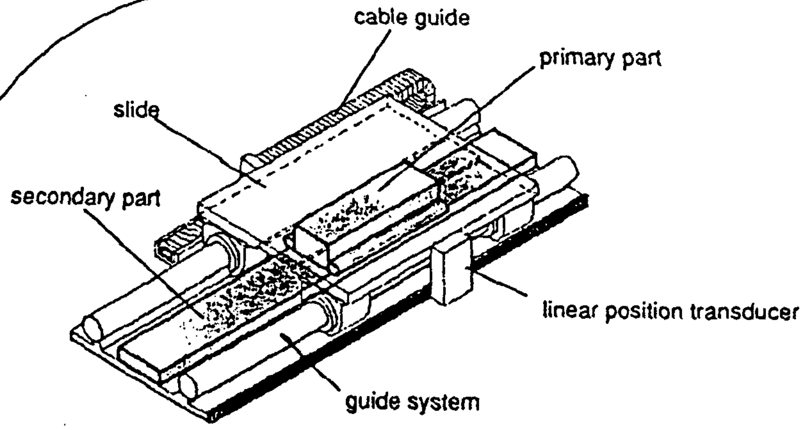
Backlash elimination and preloading in ball-bearing screws and nuts:
(a) and (b) by axial displacement of the nut sections; (c) by relative rotation of the nut sections

comparison between direct drives and conventional feed units	
+ also at high feed rates: high positional accuracy and long strokes possible	- higher system price
+ high stiffness	- more energy dissipation
+ less mass moment of inertia	- higher transition of heat from the motors to the machine bed and slide
+ good dynamic behaviour	- magnetic force of attraction 5 times higher than feed forces
+ high accelerations	
+ less components	
+ less wear	
+ long life-time	

(3) Linear motor

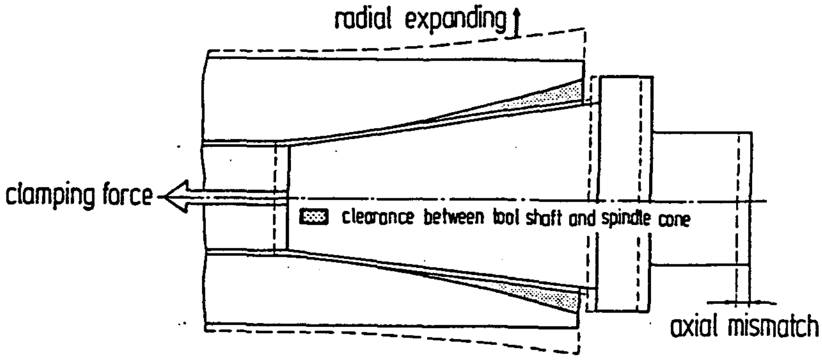
이송속도 : 150m/min

2~10G

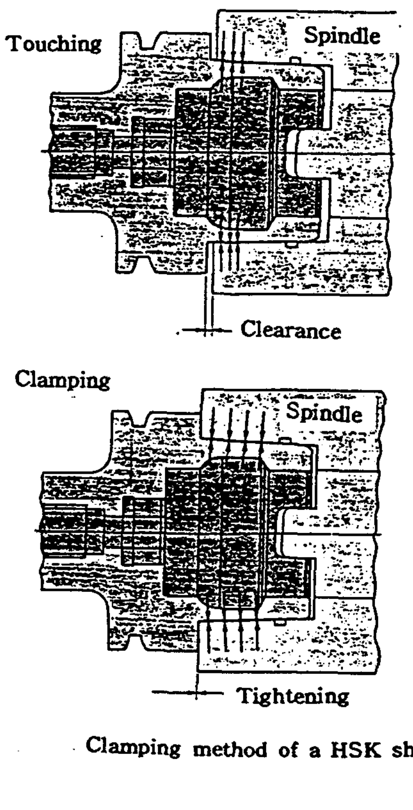


- Example "fast": Direct Drives for Feed Units

3-3 고속에 따르는 Tooling



Chuck deformations influenced by centrifugal forces



Clamping method of a HSK shank

◆ 7/24 Taper shank의 문제점

1. 스핀들이 확장된다. - 의치가 불일정
2. 단면 접촉이 없다. - 정도관리
3. Shank의 길이가 길다. - ATC에 부적합
4. Quick Release 가능

◆ 이면구속형 Tooling의 특징

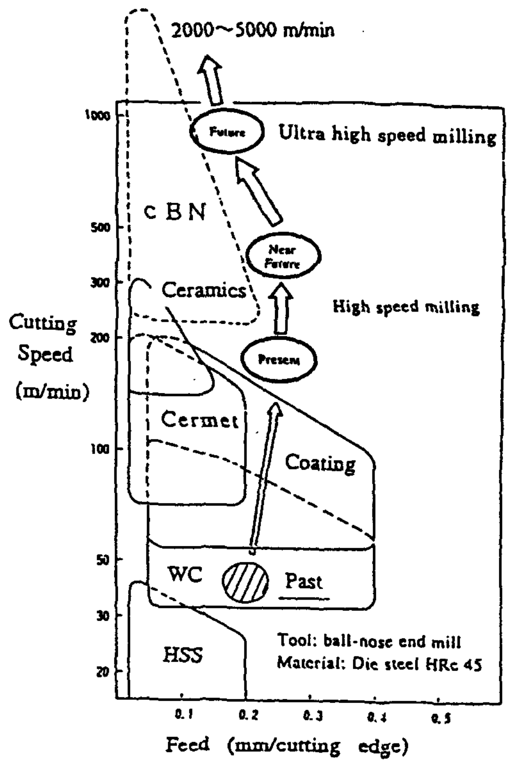
1) 높은 軸 방향의 강성과 정도
2) Radial방향의 변위가 적다.
3) Flange의 접합 강성이 높다.
4) Damping 특성
5) 진동의 발생을 억제한다.

4. 고속 밀링과 고속연삭

Name of maker	RPM (×10³)	Other specifications
NIGATA ENGINEERING *	100	Ceramic ball bearing; Tool dia=10 φ ; No ATC; f=10m/min
MORI SEIKI	70	#40; Magnetic bearing; f=60m/min; 1.3G
TOSHIBA MACHINE	50	Air bearing; Spindle dia 50 φ; f=20m/min
MATSUURA MACHINERY	40	#30; Bearing dia(Internal) 40 φ
MITSUI SEIKI KOGYO	40	#30; Spindle dia 40 φ ; f=20m/min
MAKINO MILLING MACHINE	32	Spindle dia 23 φ; Tool dia 6 φ; f=16m/min
YAMAZAKI MAZAK	25	#40; Bearing dia(internal) 70 φ; f=60m/min, 1G
KITAMURA MACHINERY	25	#40
OKUMA	25	#40

* : Developed in 1990

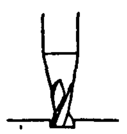
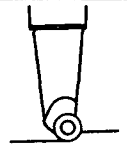
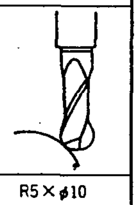
Japanese high speed milling machine in the market

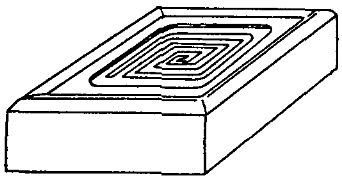


Ultra-high speed milling by cBN cutting tool

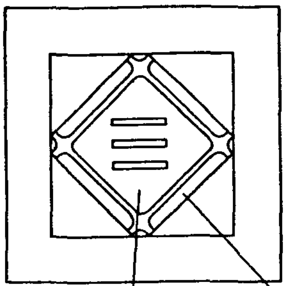
MITSUI-SEIKI

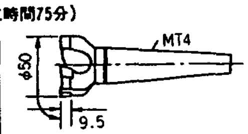
●実例2　鋼（S55C）の高速加工小径エンドミル加工

回　転　数	16000	8000	12000
送り速度	800	1200	3000
形　　状			
径	φ2	R4×φ12	R5×φ10
材　　質	サーメット	超硬コーティング	サーメット
名　　称	ミラカットエンドミル (OSG)	丸駒エンドミル (OSG)	ボールエンドミル (OSG)

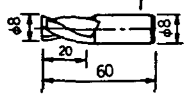


●実例3　アルミ材の高速切削（加工時間75分）

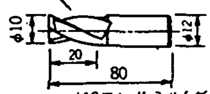




φ50正面フライス(菱高精機)
形式：MG200R504
チップ：超硬4枚
主軸回転数：1万5000rpm, 2300mm/min
送り：10m/min, 0.67mm/rev
排出量：1500cm³/min



φ8エンドミル(ダイジェット)
形式：OCES2080S(FB15)
主軸回転数：1万5000rpm, 377m/min
送り：3000mm/min, 0.2mm/rev



φ10エンドミル(ダイジェット)
形式：OCEB100(KT9)
主軸回転数：1万5000rpm, 470m/min
送り：3000mm/min, 0.2mm/rev.

ヤマザキマザック

営業企画部 小嶋

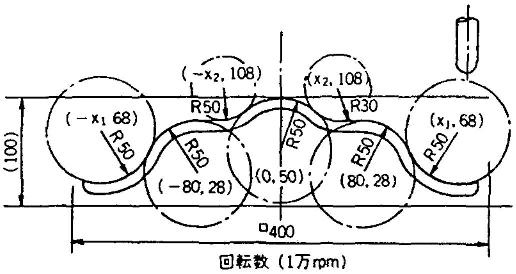
(1)門形マシニングセンタACCURA JIG MATIC AJV60/120

(2) 1万rpm（dn値90万）：セラミックアンギュラ玉軸受，オイルエア潤滑

(3) 3軸同時10m/min（1㎜ブロック33m/min相当）

(4) H630と同じ

●形状加工の素材と実績値



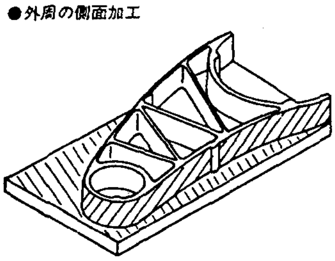
回転数（1万rpm）

被削材：6ナイロン
工具：φ30ボールエンドミル(ハイス2枚刃), 送り：15m/min(0.5mmブロック)

(5)アルミの高速エンドミル加工

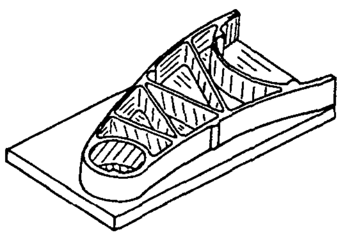
ワーク寸法1270×420×120

●外周の側面加工



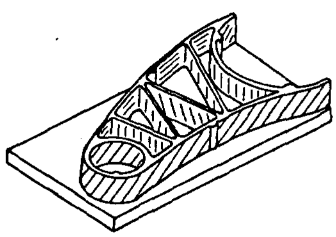
カッタ径	63mm
主軸回転数	10000rpm
切削速度	1980m/min
切り込み	12.5mm
送り	10000mm/min
切削量	5620cc/min

●ポケット加工（荒）



カッタ径	30mm
主軸回転数	10000rpm
切削速度	940m/min
切り込み	12.5mm
送り	4000mm/min
切削量	1500cc/min

●側面加工（仕上げ）



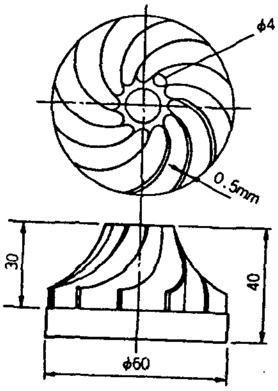
カッタ径	20mm
主軸回転数	10000rpm
切削速度	628m/min
切り込み	0.1mm
送り	2400mm/min

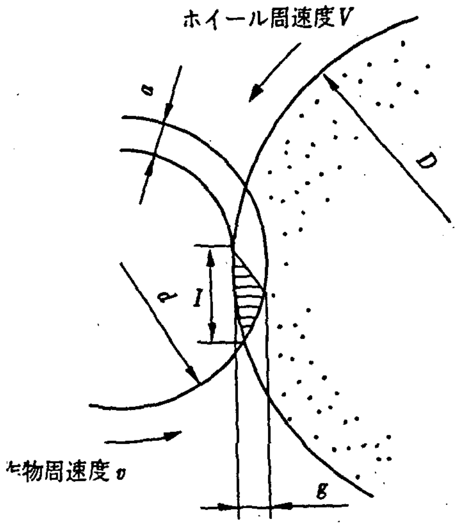
●ワーク加工例

●実例1　小径エンドミルにて深溝高能率加工

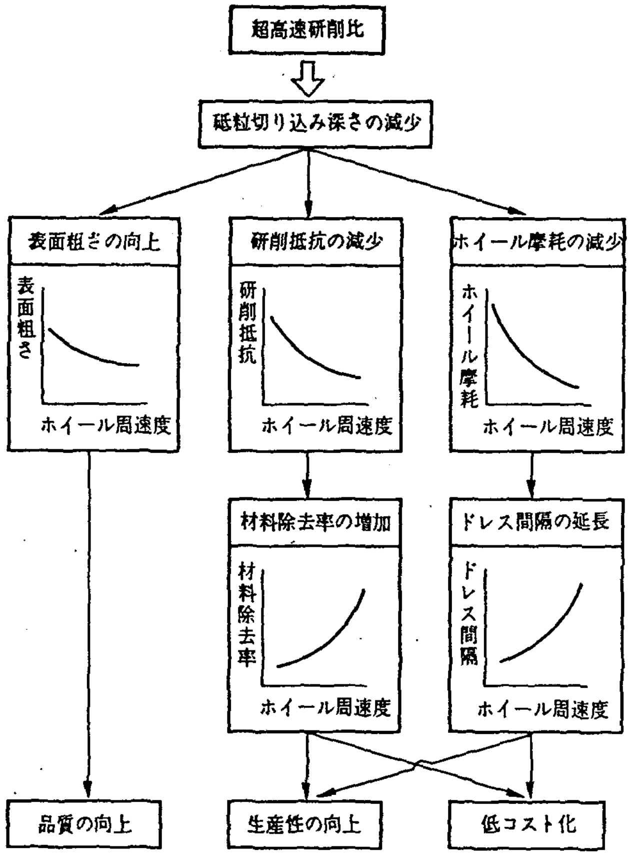
主軸回転数：2万rpm（250m/min）
送り速度：2000mm/min
加工時間：全体30分，羽根部18分
エンドミル直径：φ4 mm

材質：Aℓ6061-T6





円筒研削における研削幾何学図



超高速研削の効果

◆ 고속 연삭의 이론

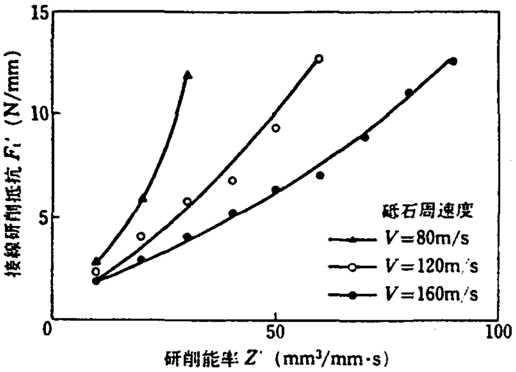
고속 연삭 일 때 최대 연삭 깊이 g와 칩의 거리 ℓ은

$$g = z\lambda \nu / V \sqrt{a(1/D + 1/d)}$$

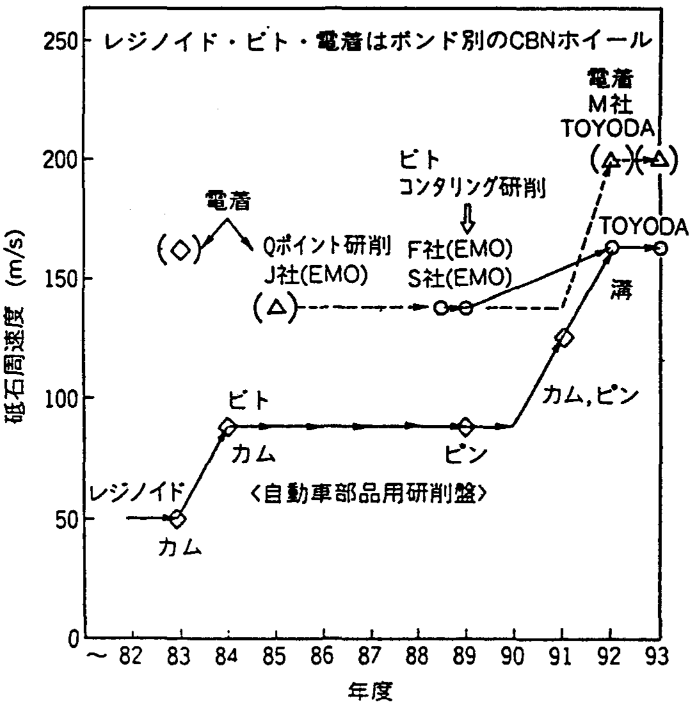
$$\ell = (1 + \nu / V) \sqrt{a(1/D + 1/d}$$

(λ = 연속 칩의 간격)

Wheel 주속도(V)를 증대시키면 grit의 절삭깊이(g)가 감소되어 qrit한게 단부가저 감소된다. 그 결과 연삭저항(F)가 감소되고, Wheel의 수명이 연장된다. 역으로 grit에 미치는 부가가 감소되는 만큼 연삭능률(Z)을 높일 수 있고, 고능률, 고생산성을 실현시킬 수 있다.



砥石周速度に対する研削能率と研削抵抗の関係



高速研削の動向

Machine base, guides and drives

- high static stiffness
- uncritical dynamic behaviour
- high accuracy (repeatability)
- high-dynamical drive units

Grinding spindle

- high spindle speed and power
- optimized tool interface (HSK)
- monitoring capability (e.g. AMB spindle)

CBN grinding wheels

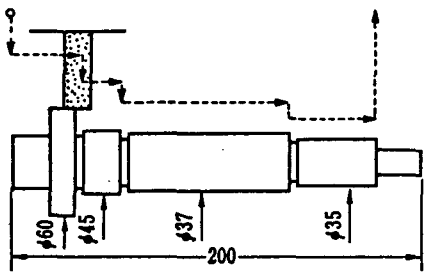
- optimized wheel body (material, shape)
- adapted CBN layer (bond, grits)

Components, periphery

- CNC control with intelligence
- roller dressing units with AE sensor
- adapted coolant supply system
- automized process monitoring
- automized workpiece handling
- CNC control with intelligence

Safety measures

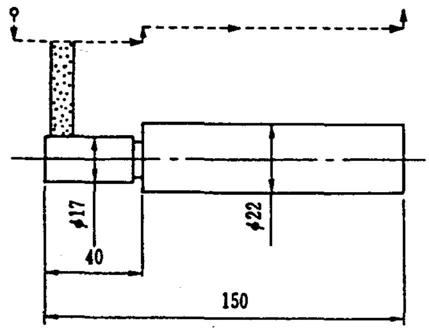
- closed machine capsule
- oil mist exhaust devices



<ホイール>φ400×15T×3X×φ25H
HIG-V (BN80J200HV2)
<R　　D>φ100×1T×3X×φ8H
SD40P75M
<工　作　物>シャフト，材質：SCM435，H_RC 50±3
取りしろ：φ0.3mm
<機　　械>豊田工機製超高速円筒研削盤 GZ32P
<ドレス条件>ホイール周速度：160m/s
R D 周速度：80m/s
切り込み深さ：φ5μm/パス
送　り　量：0.2mm/rev
<研削条件>ホイール周速度：160m/s
工作物回転数：500min⁻¹
切り込み深さ：φ0.3mm（1パス加工）
コンタリング量：0.2mm/rev
研　削　液：JIS W1，20倍希釈液
<加工結果>

		(要求)
寸法精度 〔μm〕	≦φ5	≦φ10
真円度 〔μm〕	0.7～1.2	≦3
円筒度 〔μm〕	1	≦3
表面粗さ R_z〔μm〕	1.2～1.6	≦3.2
サイクルタイム〔s〕	75	105
実研削時間 〔s〕	58	—

焼入れシャフトのコンタリング研削



<ホイール>φ400×10T×3X×φ25H
HIG-V(BN80G200HV2)
<R　　D>φ100×1.2T×3X×φ8H
SD40P75M
<工　作　物>シャフト，材質：S45C，H_RC 18
取りしろ：φ1mm
<機　　械>豊田工機製超高速円筒研削盤 GZ32P
<ドレス条件>ホイール周速度：160m/s
R D 周速度：80m/s
切り込み深さ：φ5μm/パス
送　り　量：0.3mm/rev
<研削条件>ホイール周速度：160m/s
工作物回転数：1,500min⁻¹
切り込み深さ：φ1mm（1パス加工）
コンタリング量：0.3mm/rev
研　削　液：JIS W1，10倍希釈液
<加工結果>
寸法精度 〔μm〕：≦φ10
真円度 〔μm〕：2～7
円筒度 〔μm〕：2～4
表面粗さ R_z〔μm〕：3～7
研削焼け，割れ：なし
サイクルタイム〔s〕：28

生材シャフトのコンタリング研削

5. 환경친화형 공작기계

- 加工時間中の省エネ
  - 高 速 化 ：高速化による加工時間短縮により消費電力量を削減
  - 小 型 化 ：機器の小型化、省配線化を通じた消費電力量削減
  - 機構の変更 ：機構部分の見直しによる消費電力の削減
    - ・油圧ユニットの廃止
    - ・主軸冷却をオイルクーラーから風洞冷却に変更
    - ・主軸の潤滑をミスト方式に変更、エア用電力を削減
    - ・変速機の採用で、モーターを高効率回転数に維持しつつ主軸の高速回転を実現
    - ・クーラント使用量の削減により、同ポンプなどを小型化して消費電力を削減
    - ・ポンプにインバータモニターを採用 等
- 非加工時間中の省エネ
  - 高速化 ：MCの工具交換時間の短縮などを通じて段取り工程時の消費電力量削減
  - 待機電力削減：機械の熱変位に対するロバスト性の向上を通じて、ウオーミングアップ等の空運転を不要化

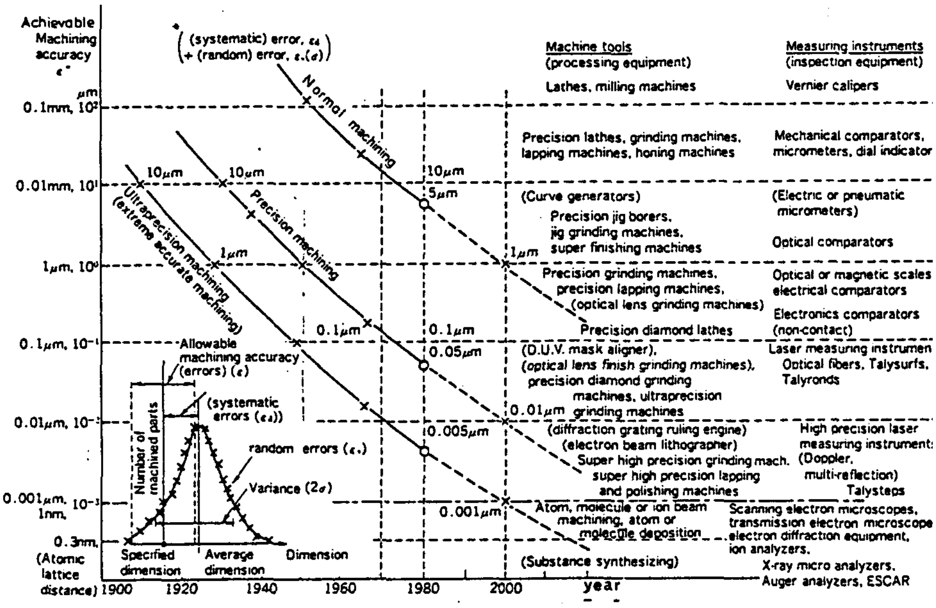
에너지절약 공작기계

企業		日立精機				A社		B社	
項目	単位	VS50 仕様	負荷 ポイント	VK45 II仕様	負荷 ポイント	仕様	負荷 ポイント	仕様	負荷 ポイント
主軸出力	Kw	11		7.5		22		7.5	
Xストローク	mm	1000		760		800		560	
電源容量	KVA	18	3	22	3	47.9	7	19	3
作動油量	L	0	1	40	3	0	1	15	2
主軸冷却油量	L	15	2	20	2	50	3	18	2
潤滑油量	主軸用 L	0	1	1.3	3	0.8	3	0.8	3
	LM BS用 L	0	1	主軸と兼用	1	4.2	5	主軸と兼用	1
空気所要量	L/min	100	1	200	2	350	3	500	3
幅＊奥行き	mm	2900*2400		2400*3150		2373*2695		1800*2380	
機械高	mm	2785		2628		3020		2650	
設置面積	m^2	7	3	7.6	3	6.4	3	4.3	2
機械質量	kg	8200		6500		7800		5000	
環境負荷ポイント計		12		17		25		16	

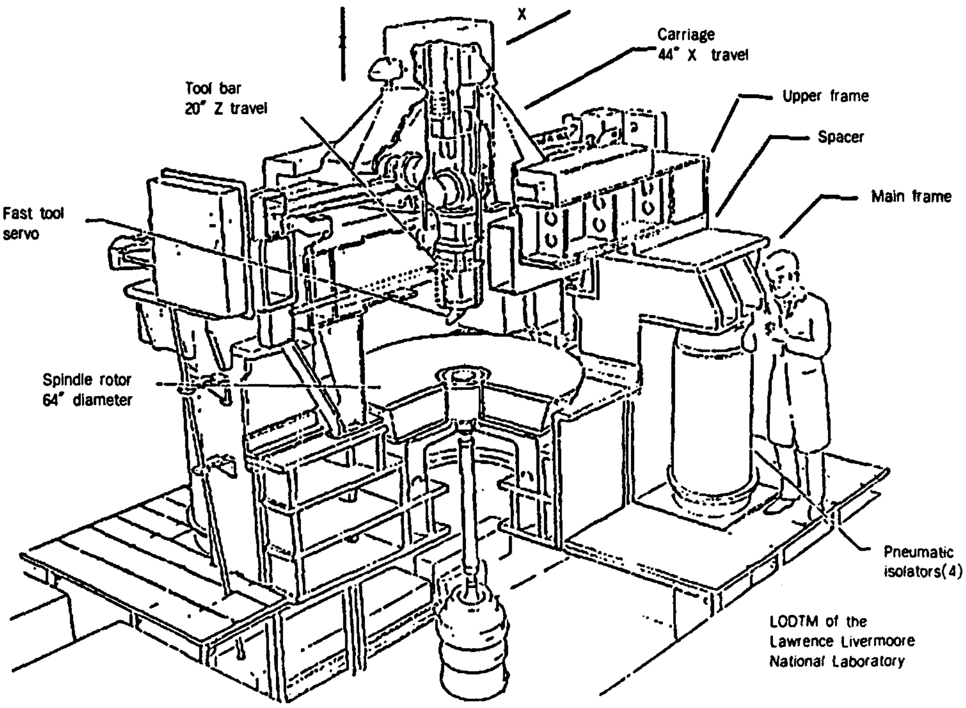
(出所) 日立精機 SEIKI TECHNICAL NEWS 1998 VOL. 95

공작기계의 환경부과 표준화

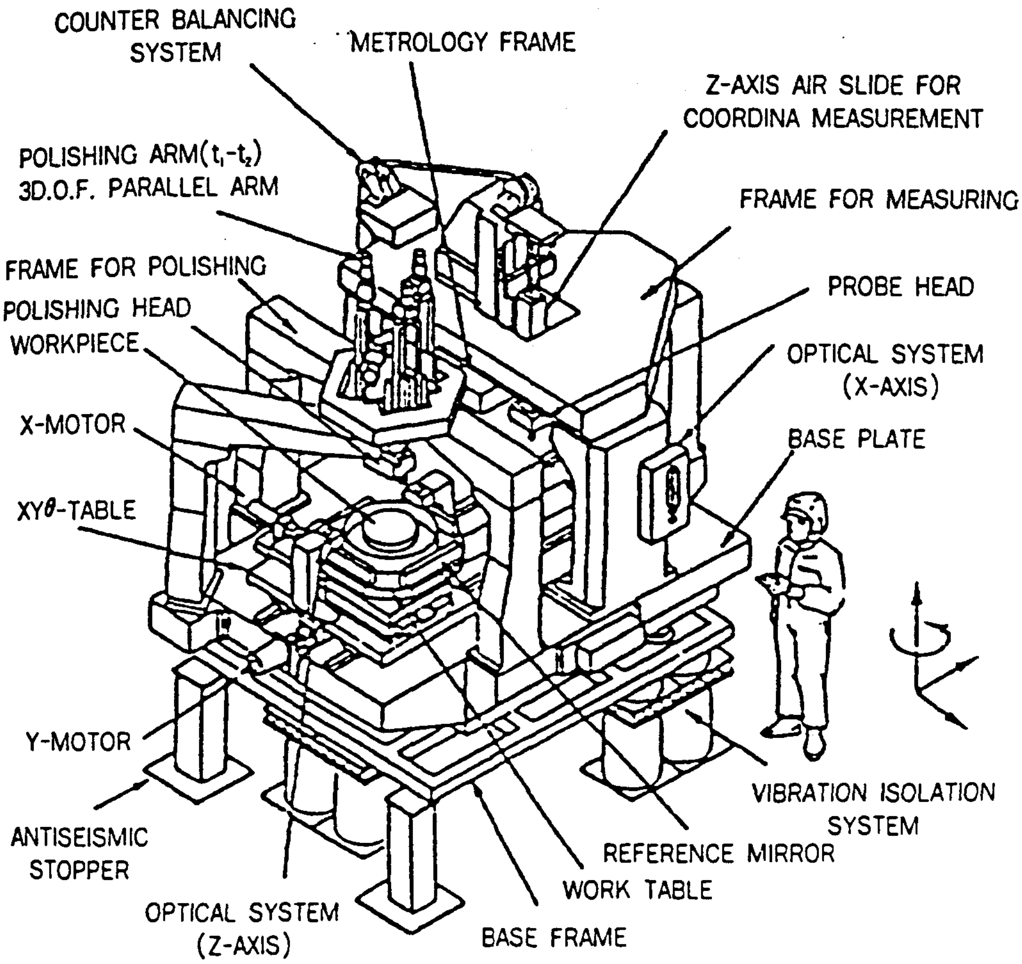
6. 초정밀공작기계



The development of achievable machining accuracy



LODTM of the LLNC

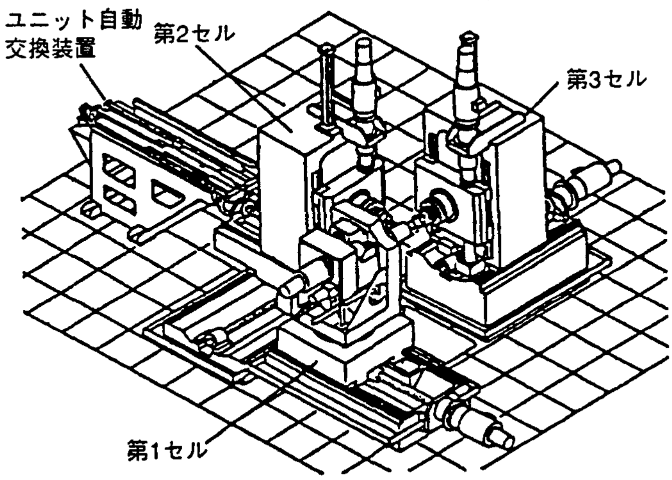


High precision coordinate measuring and corrective polishing system CSSP

7. 복합화 공작기계

主 軸 配 置

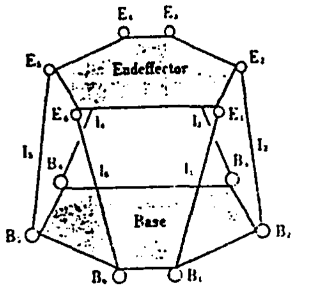
	加工セル配置 (作業コンビネーション)	作業コンビネーション略称	作業コンビネーションでの加工処理機能例
1	(2セルコンビネーション)	I形	・最大2面加工が可 ・平板、円板加工に適
2	(同上)	L形	・最大4面加工が可 ・角物、円筒加工に適
3	(3セルコンビネーション)	T形	・最大6面加工が可 ・同時6面加工が可 ・軸物、角物加工に適
4	(4セルコンビネーション)	X形 (クロス)	・最大6面加工が可 ・同時3面加工が可 ・接近性に劣る
5	(同上)	(T+I) 形	・2部品同時加工が可



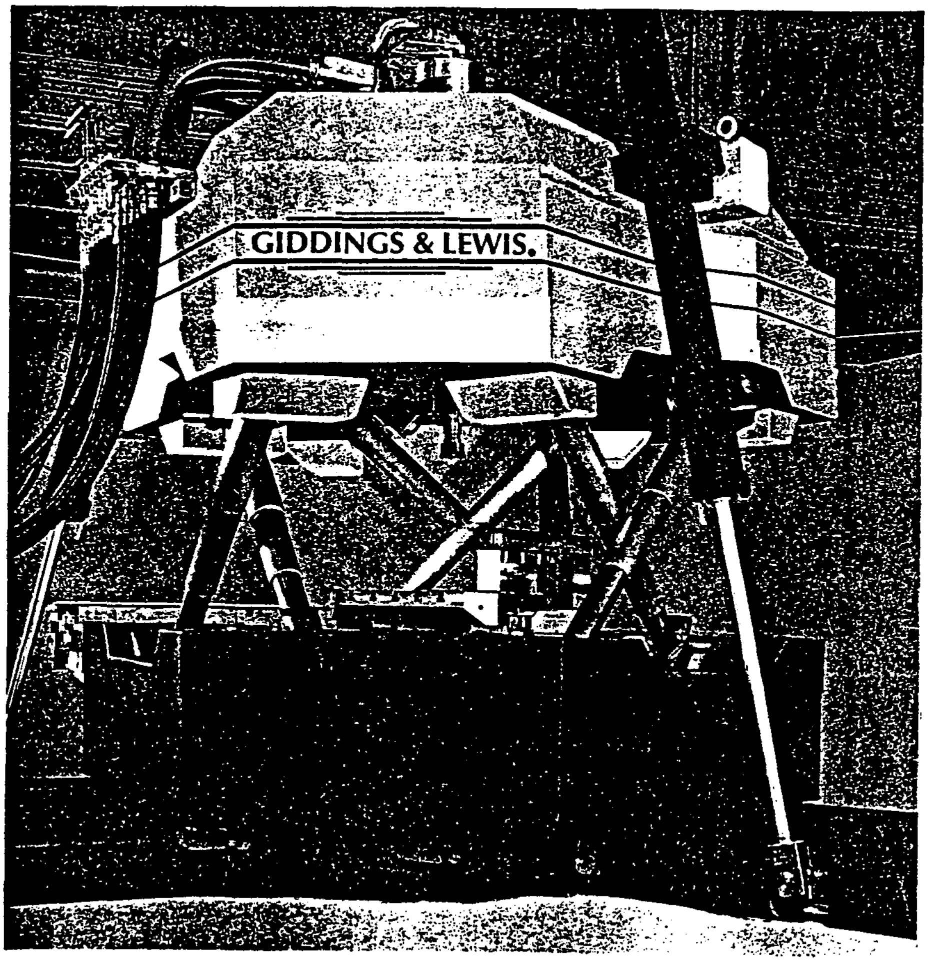
第1セル	コラムの左右移動 (X軸)
	コラムの旋回 (B軸)
第2セル	コラムの左右移動 (X軸)
	コラムの前後移動 (Z軸)
	サドルの上下移動 (Y軸)
第3セル	コラムの前後移動 (Z軸)
	サドルの上下移動 (Y軸)

複合切削装置全体図 (Tセル)

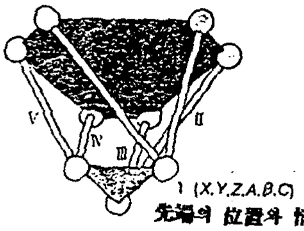
8. 신개념 공작기계

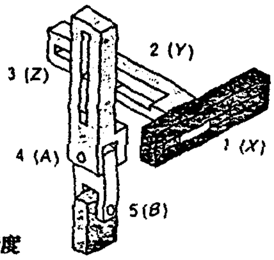


Concept of the Steward platform



Giddings & Lewis Co's, VARIAX





先端의 位置와 精度

座標		誤差
位置	X	1~6の平均
	Y	1~6の平均
	Z	1~6の平均
姿勢	A	1~6の平均
	B	1~6の平均
	C	1~6の平均

Parallel mechanism

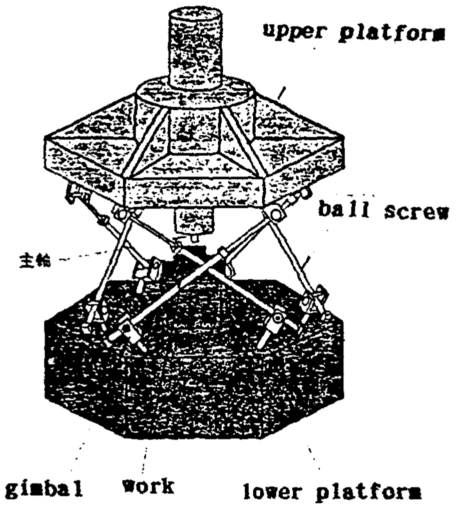
座標		誤差
位置	X	1
	Y	2
	Z	3
姿勢	A	4
	B	5

serial mechanism

Position and location errors by two mechanism

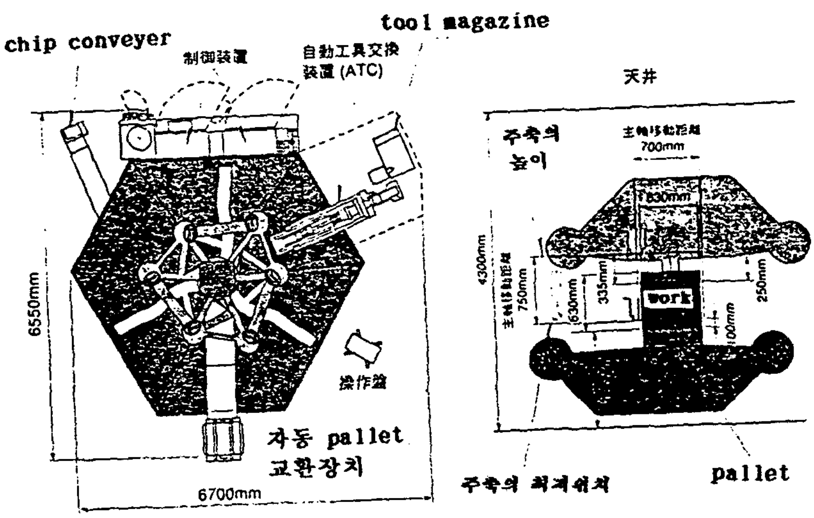
比較項目	Parallel mechanism	Serial mechanism
作業領域	적다	크다.
順運動学	困難	容易
逆運動学	容易	困難
順静力学	容易	困難
逆静力学	困難	容易
位置誤差	평균화한다	누적한다
力誤差	누적한다	평균화한다
最大力	全 Actuator의 出力을 加算한다	最小Actuator에 의해서 制限된다.
剛性	크다	적다
動力学	매우 복잡	複雑
慣性	적다	크다

Parallel mechanism compared with serial mechanism



Feed = 100m/min
RPM = 24,000　　G = 14m/s(1.5G)

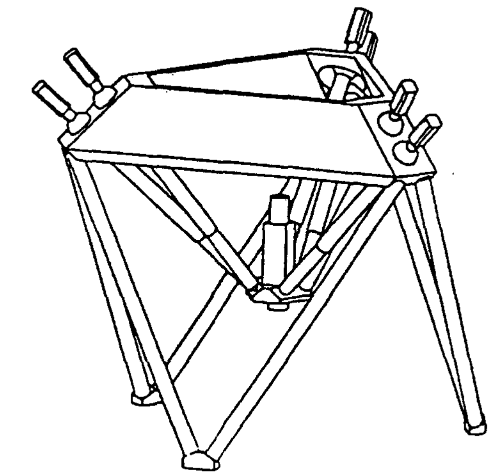
Conceptional steward platform for machine tool design



Giddings & Lewis Co's machining center based on parallel mechanism

Advantages

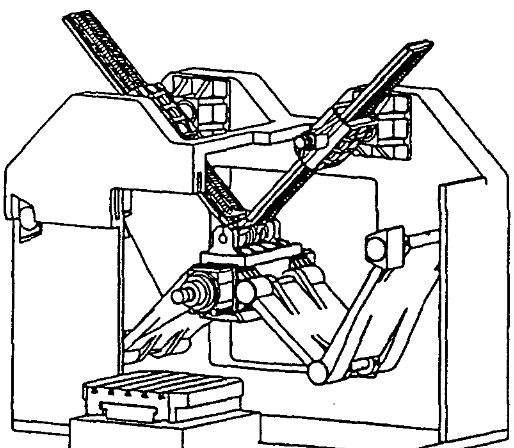
- inherent stiffness
  ⇒ no basement required
- only tensile or pressure load of actuator and tramecomponents
- low requirements on manufacturing and assembly-accuracy of the frame
  ⇒ real joint-locations can be determineed in the realized machine and be considered in the control
- simple frame-components
  ⇒ low manufacturing costs
- 6 identical linear-drives
  ⇒ repetition parts



Disadvantages

- also simple liner movements require a six-axis-control
- extensive control expenditures
  ⇒ transformation of coordinates
  ⇒ collision monitoring
- limited orientation mobility of the tool
- six drive-devices
- large effective thermal strut-length
- disadvantageous ratio of working-room to machine-room
- difficult calibration needed

Advantaged and disadvantages of parallel kinematics



machine structure

hybrid-kinematic
coupler mechanisim as parallel structure
with serial topped z-ram

3-axes-machine especially for the use
in transfer-lines

specification

working-room	
630 × 630 × 500 mm^3	
feed-drives	
velocity	90m/min
acceleration	1.5g
feed-forque	10kN
main-spindle	
max. speed	16.000min^{-1}
max. torque	45 Nm at 3000min^{-1}
spindle-power	15kW
minimum stiffness	
x-/y-direction:	30N/μm
z-direction:	60N/μm

; Hybrid kinematic based on a coupler mechanism:Dyna-M(WZL)

9. 시스템화 (FMS, CIM)

Function	Individual machine			Multi-machine system	
	M/C	NC-M/C	MGC	DNC	FMS
Tool change	○	○	●	(●)	●
Tool transport	○	○	○	○	(●)
Workpiece change	○	○	●	○	●
Workpiece transport	○	○	○	○	●
Control data distribution	○	◐	◐	●	●
Operating data collection	○	○	○	●	●
Process monitoring	○	○	○	●	●

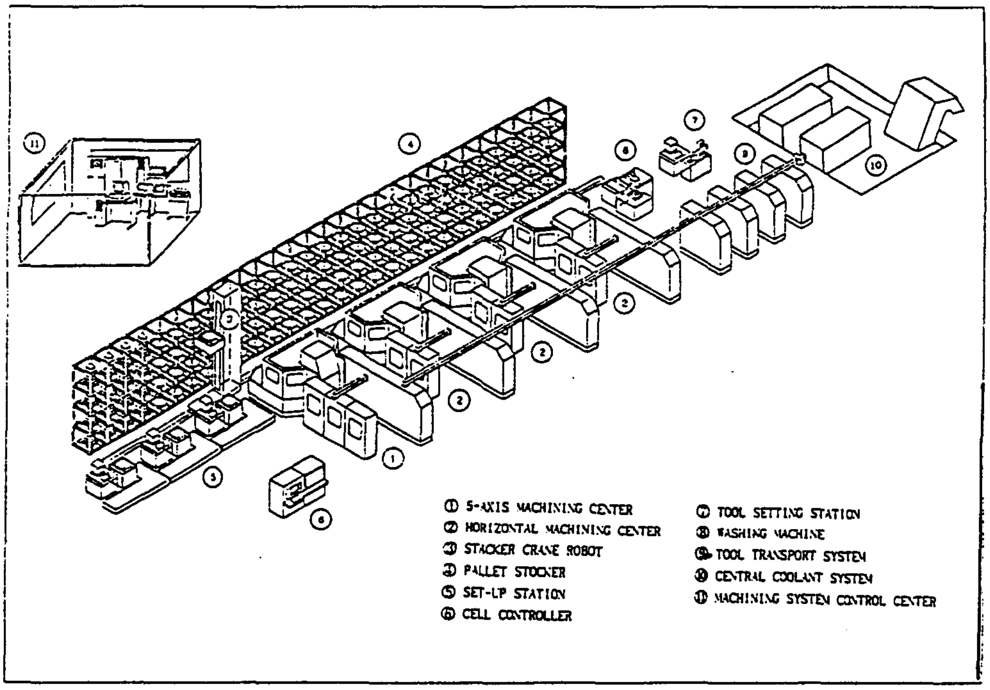
M/C : Machine tool

MGC : Machine centre

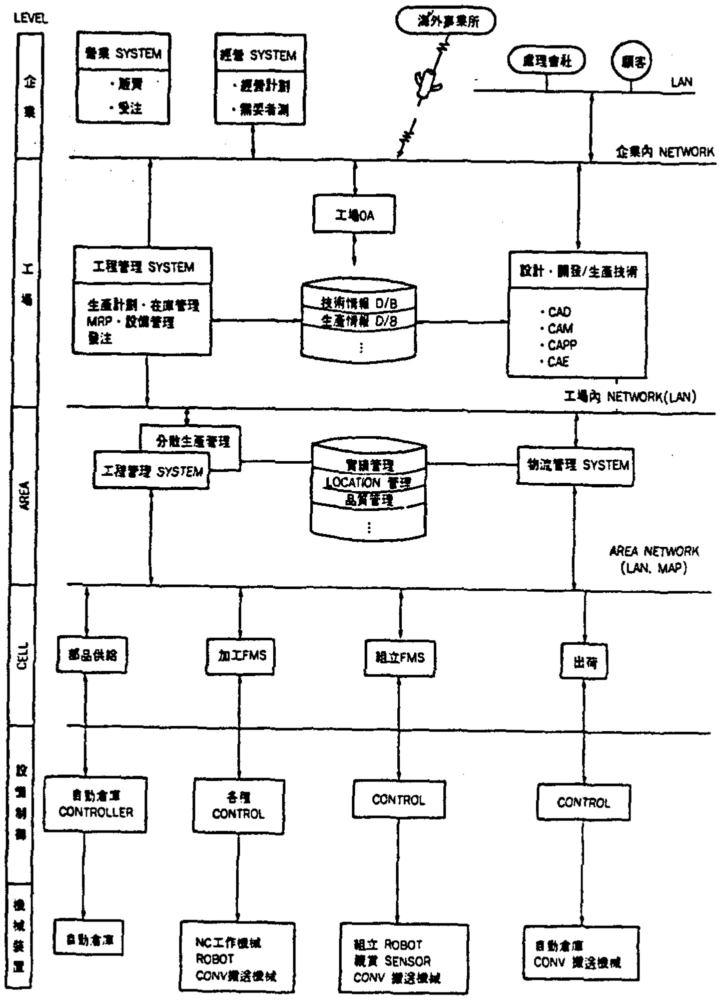
FMS : Flexible manufacturing system

● ◐ ○ ↑ Increasing automation

Stages in automation of production

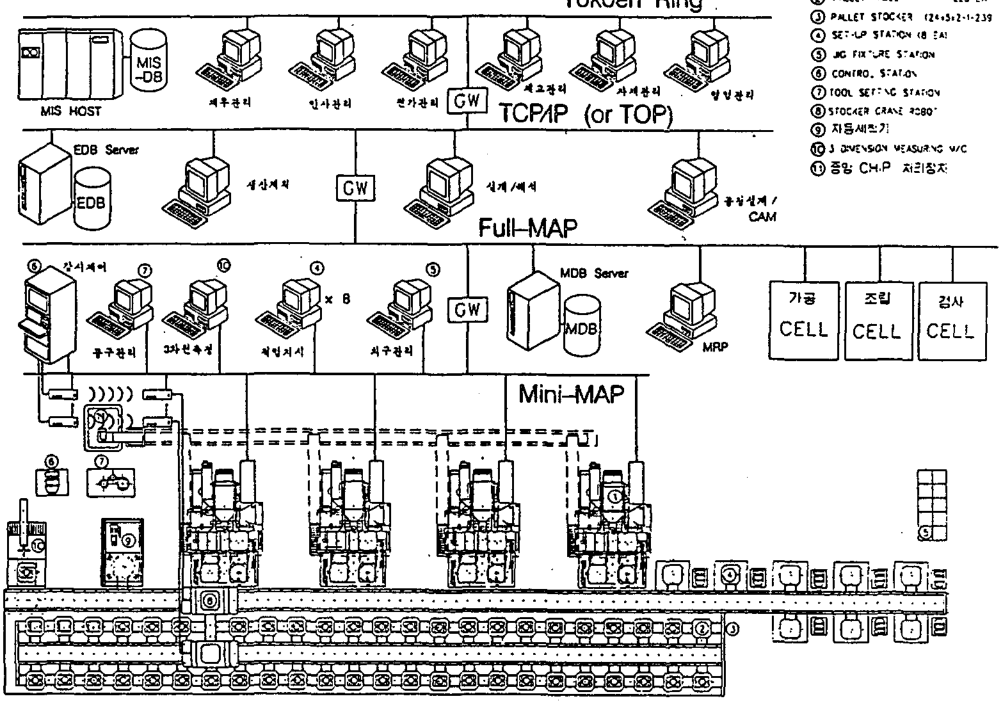


TONG-IL's flexible manufacturing system



ISO's CIM structure

CIM 통신망구성도


Tokoen Ring
MIS HOST
MIS -DB
재무관리
인사관리
원가관리
GW
재고관리
자재관리
영업관리
TCP/IP (or TOP)
EDB Server
EDB
생산계획
GW
설계/해석
공정설계 / CAM
Full-MAP
⑥ 감시제어
⑦
⑩
④
× 8
⑤
공구관리
3차원측정
작업지시
치구관리
GW
MDB Server
MDB
MRP
가공 CELL
조립 CELL
검사 CELL
Mini-MAP
① MACHINING CENTER (4 EA)
② PALLET TABLE 225 EA
③ PALLET STOCKER (24+5+2-1-239
④ SET-UP STATION (8 EA)
⑤ JIG FIXTURE STATION
⑥ CONTROL STATION
⑦ TOOL SETTING STATION
⑧ STOCKER CRANE ROBOT
⑨ 자동세척기
⑩ 3 DIMENSION MEASURING M/C
⑪ 중앙 CHIP 처리장치

10. 결 론

1. 공구재료의 발달이 초고속가공을 가능케 함으로서 공작기계를 고속화하게 하였다.
2. Bearing 발달이 Spindle의 회전수를 수만회전을 가능케 하고있고 이송 속도도 고속화하고 있다.
3. Spindle의 고속화는 Tooling의 새설계가 요구되고 있다.
4. 환경친화형 공작기계, 초정밀공작기계가 보급되어 가고있다.
5. Spindle Head와 Feed mechanism을 복합화 함으로서 복잡한 가공을 가능케 하고 있다.
6. Parallel mechanism을 이용하는 새개념 공작기계가 보급되고 있다.
7. 생산공학이 System화 되고있으며 FMS, CIM가 발달되고 있다.
8. 이 강연에서 언급되지 않았지만 공작기계 발전을 위하여 다음 항목의 기술발전이 필수적이다.
   1) 열변위의 보정기술
   2) CAE을 이용하는 설계기술
   3) Simulation 기술의 응용