行政院及所屬各機關出國報告
（出國類別：考察）

赴瑞典、德國參訪刀具廠
及工具機展心得報告

服務機關：中山科學研究院
出國人職稱：薦任技正
薦聘技正
薦聘技士
姓名：柯明闊
陳盛基
吳家振

出國地區：瑞典、德國
出國期間：90.09.08～90.09.17
報告日期：90.12.25

CSIPW-90B-F0009

國外公差報告

(91)[illegible]022 號

中山科學研究院

國外公差心得報告

批示				
中山科學研究院 副院長 仲澤 0411 0850；中山科學研究院 副院長 宋大偉 0515 1205；建議事項依企劃處意見辦理。				
公差年度	90	所屬單位各級主管	政戰部	企劃處
單位	二所總廠工發組 二所總廠廿一廠	第二研究所 代理副所長兼總廠長 許覺良 0204 1330；第二研究所 所長 蘇玉 0204 1030	已完成資料審查	如簽會意見。 企劃處 處長 陳 0404 1600
級職	荐聘技正 荐聘技士 荐任技正			
姓名	陳盛基 吳家振 柯明闊	第二研究所 第廿一廠廠長 李學志 0121 1645；第二研究所 工程發展組 副組長 林英 0128 1010	政治作戰部 保防員 顧中 0601 0825；政戰部 組長 劉智 0910	企劃處 技正 蔣雅 1250；企劃處 技術推廣組 副組長 邱炎川 1315

0010007

國外公差人員返國報告主官（管）審查意見表

本院執行經濟部科技專案，其中目的之一即以本院先進技術，指導民間廠商突破研發瓶頸，產製高科技、高技術層面、高單價、高附加價值之先進產品。為達此目的，本院之研發人員必須具備最新的技術新知，商情資訊及市場動態等瞬息萬變的科技商情，因而於每年計畫擬定之時，即計畫安排人員出國赴歐美等先進國家蒐集新技術、新產品、新動向等資訊，以便掌控先機，同步發展。

柯、陳、吳三員本次奉派出國，其主要目的即為蒐集經濟部科專案分項計畫之相關商情資訊，該三員參訪瑞典 SANDVIK 刀具廠、德國 ZEISS 公司及 INGERSOL 公司，並且參觀 2001 年德國漢諾威工具機展。與上述公司討論難削材刀具之選用，光學量測儀器與鏡片之製程設備，及先進工具機之最新發展趨勢。並與廠商針對超合金與鈦合金切削刀具之選用及切削參數之選擇，進行技術性之討論；在 EMO 展覽會上，針對線性馬達在工具機之應用技術進行細節討論，對液靜壓主軸與滑軌等關鍵性零組件，與廠商洽談技術合作與轉移之可行性，對總廠後續執行先進工具機計劃，提供多項新觀念與關鍵技術，確已達到派遣出國目的。

第二研究所 所長 蘇[illegible]

依本院 85.11.25（85）蓮菁字 15378 號令，返國報告上呈時應附主官評審意見

報 告 資 料 頁

1. 報告編號： CSIPW-90B-F0009	2. 出國類別： 考察	3. 完成日期： 90 年 12 月 25 日	4. 總頁數： 24

5. 報告名稱：
赴瑞典、德國參訪刀具廠及工具機展心得報告

6. 核准文號	人令文號	(90)蓮萌字第 09285 號
	部令文號	(90)銓鑑字第 005979 號
7. 經費		新台幣：參拾壹萬柒仟參佰肆拾玖元整
8. 出(返)國日期		90.09.08 至 90.09.17
9. 公差地點		瑞典、德國
10. 公差機構		瑞典 SANDVIK 刀具廠及 德國漢諾威 EMO 工具機展
11. 附記		

附件二

系統識別號

行政院及所屬各機關出國報告提要

出國報告名稱：赴瑞典、德國參訪刀具廠及工具機展心得報告

頁數 24 含附件：☑是□否

出國計畫主辦機關/聯絡人/電話：

國防部中山科學研究院/吳家振/(03)4712201 轉 352179

出國人員姓名/服務機關/單位/職稱/電話：

柯明闊/二所廿一廠/荐任技正/352146

陳盛基/二所工發組/荐聘技正/356727

吳家振/二所廿一廠/荐聘技士/352179

出國類別：☑1 考察□2 進修□3 研究□4 實習□5 其他

出國期間：
90.09.08～90.09.17

出國地區：
瑞典、德國

報告日期：90.12.25

分類號/目

關鍵詞：超合金、難削材、線性馬達、液靜壓滑軌、液動靜壓主軸

內容摘要：(二百至三百字)

本篇報告為參訪瑞典 SANDVIK 刀具廠，研討飛彈火箭發動機外殼所使用之難削材，Ti-6Al-4V 鈦合金及 INCONEL 718 超合金之切削刀具及參數選用，將本廠目前加工此類材料所遭遇之技術瓶頸，先彙整後請 SANDVIK 原廠工程師依所提問題，提出解決對策與安排現場示範，經與原廠人員研討後，已尋得最佳之刀具及切削參數，並攜回多份難削材加工技術資料，對提昇本廠加工難削材之能力，提供了具體可行之建議。

本報告之另一重點為參觀 2001 年德國漢諾威工具機大展(EMO 展)之心得報告，本次出國之三員在行前均依個人專長分派任務，分別負責蒐集先進工具機之發展趨勢與關鍵技術，包括線性與內藏式馬達、熱補償與 FRP 機體結構、高速加工系統、液動靜壓主軸及滑軌系統等相關技術與零組件，在 EMO 展覽會上，成員均依事先之規劃蒐集到完整之資料與技術，相信對未來軍通案之規劃與執行，會有莫大之助益。

本文電子檔已上傳至出國報告資訊網（http://report.gsn.gov.tw）

附件三

行政院及所屬各機關出國報告審核表

出國報告名稱：赴瑞典、德國參訪刀具廠及工具機展心得報告	
出國計畫主辦機關名稱：國防部中山科學研究院	
出國人姓名/職稱/服務單位：二所總廠廿一廠荐任技正柯明闊等 3 人	
出國計畫主辦機關審核意見	☐1. 依限繳交出國報告 ☑2. 格式完整 ☑3. 內容充實完備 ☑4. 建議具參考價值 ☑5. 送本機關參考或研辦 ☑6. 送上級機關參考 ☐7. 退回補正，原因：☐①不符原核定出國計畫 ☐②以外文撰寫或僅以所蒐集外文資料為內容 ☐③內容空洞簡略 ☐④未依行政院所屬各機關出國報告規格辦理 ☐⑤未於資訊網登錄提要資料及傳送出國報告電子檔 ☑8. 其他處理意見：本案屬非密類一般件，奉核後紙本請裝訂四份送本組轉發相關業管單位.
層轉機關審核意見	☐同意主辦機關審核意見 ☐全部 ☐部分＿＿＿＿＿＿（填寫審核意見編號） ☐退回補正，原因：＿＿＿＿＿＿＿＿（填寫審核意見編號） ☐其他處理意見：

綜管組：

政戰室：

第二研究所保參官 羅琳

第二研究所副組長 唐國銘

第二研究所 李嘉華

說明：

一、出國計畫主辦機關即層轉機關時，不需填寫「層轉機關審核意見」。

二、各機關可依需要自行增列審核項目內容，出國報告審核完畢本表請自行保存。

三、審核作業應於出國報告提出後二個月內完成。

中山科學研究院公差出國人員報告目錄

附件5件

壹、出國目的及緣由

近年來，工具機朝向高速及高精度的方向發展，為求高速驅動，乃採用線性馬達為其主要之驅動系統，為求高精度所以採用液動靜壓主軸及液靜壓滑軌傳動。本廠為掌握其發展趨勢，於經濟部科專計畫建立「先進工具機系統」研製案，其採用之驅動與傳動系統功能及規格完全是針對次世代工具機之需求訂定。

瑞典 SANDVIK 刀具廠為世界知名的刀具製造廠商，是世界上最大的燒結碳化物切削刀具廠，該廠設有航太部門，專門負責航太業零組件切削加工問題之解決。本院採用 SANDVIK 刀具廠之刀具已行之有年，隨著各計畫逐步採用超合金、鈦合金、麻時效鋼等高溫及高強度合金之趨勢，在現場加工方面，對這些難削材之切削刀具及切削參數之選擇尚在摸索之階段，因此本次出國之重要目的之一，為將這些材料在加工刀具及技術上之瓶頸，與 SANDVIK 刀具廠之切削試驗及研發部門，透過面對面討論與現場實作示範，尋求最佳之切削刀具與合理之切削參數。

當然軍民通用之科專計畫，在總廠已經執行多年，總廠之主要建案計畫在精密工具機之研發，與先進工具機所採用之關鍵技術與零組件之建立與研製。為了使研發能與世界先進國家技術同步，此行之另一個目的為參觀每四年一次在德國漢諾威所舉行的 EMO-2001 年工具機大展，藉展覽會場上觀摩先進工具機之發展趨勢與相關零組件目前之研發水準，同時蒐集各大工具機廠商之技術資料與型錄，並與相關廠商研討解決執行中之計畫所遭遇的技術瓶頸，對計劃之遂順執行與訂定未來建案計畫之方向與規格，均有莫大之助益。

本次出國之目的，除與 SANDVIK 刀具廠研討難削材之切削技術外，並參訪德國漢諾威 EMO 工具機大展，對本院未來各先進飛彈之加工製造，提供具體可行之解決對策；同時對總廠軍通計畫案之執行與建案，也提供了解決之方案與未來發展之趨勢。

貳、公差心得

一、EMO 工具機展心得

(一)液靜壓主軸及滑軌

配合近年來產業界為求更快、更精確之加工機具及減少加工道次與加工時間，各種高速加工機紛紛出籠，如高速車床、高速磨床等等。為達到高速之目的，首先必須採用能達到 10000 轉以上之高速主軸，驅動也需由傳統之導螺桿及油壓缸逐漸導入直接驅動之線性馬達；為達到精密之要求，工具機滑軌也由傳統之硬軌、V 軌與平軌，改採以液壓或氣壓潤滑之靜壓滑軌。因此之故，總廠之先進工具機計畫中，針對精密磨床計畫研製案中建案了一個〝次微米磨床〞分計畫，該磨床即規劃採用精密的液動靜壓主軸與液靜壓滑軌來傳動。在 EMO 展中，即針對此型式之主軸與滑軌之設計製造與發展趨勢，廣泛蒐集資料並與廠商深入淺出之研討。使用液動靜壓與主軸與滑軌主要有下列之特點：

(1)高負荷能力及高剛性

負荷能力與剛性是軸承之基本性能，尤其是工具機之軸承，雖然滾動軸承有優良之負荷能力與剛性，但液體靜壓軸承具有更佳之負荷及剛性，如表 1 所示。

(2)運動精度高

超精密工具機或精密量測儀器需要有高精度之軸承，因為液靜壓軸承在軸與軸承間之潤滑油膜具有〝潤滑薄膜之均化效果〞故有緩和軸與軸承面間之形狀誤差，並發揮平滑之運轉效果，故其運動精度如表 1 所示非滾動軸承所能比擬。

(3)衰減性佳

軸承之衰減性會影響到裝有軸承之主軸系成工作檯面，若工具機使用之軸承衰減性差，在加工時會產生輕微振動而無法加工，而液靜壓軸承因為採用潤滑油作潤滑劑，因油膜之擠壓作用，故其衰減性佳，如表 1 所示。

表 1.各種軸承之性能比較

	滾動軸承	油潤滑		氣體潤滑		磁性軸承
		動壓軸承	靜壓軸承	動壓軸承	靜壓軸承	
運動精度	○	○	◎	○	◎	○
負載容量	◎	○	◎	×	○	×
靜剛性	◎	○	◎	×	○	×
衰減性	×	◎	◎	△	△	△
高速回轉	×	◎	◎	△	△	△
溫度上昇	○	×	△	◎	◎	◎
保養性	◎	○	△	○	△	○
壽命	△	△	◎	△	◎	◎
成本	◎	○	×	△	×	×

◎：特優　○：優　△：普通　×：普通

(4)使用速度範圍廣

靜壓軸承適用從低速至高速範圍之運轉，尤其是氣體靜壓軸承，因採用低粘度之空氣為介質，在高速旋轉時生熱較少，而液體靜壓軸承因高速時之摩擦功率大，會有生熱之問題，但其高速回轉仍較滾動軸承佳，如表 1 所示。

(5)壽命長

液體靜壓軸承在使用時以油膜隔離軸承與主軸，因此理論上無磨損之問題，故與滾動軸承相比，其壽命可說是半永久性的，如表 1 所示。

(6)保養較不易

因為液靜壓軸承元件仍未規格化，雖然軸承本身不需保養，但其週邊設備如節流器、過濾器均需保養或維修，與滾動軸承相比，保養較不易，如表 1 所示。

(7)價格高

因滾動軸承不需要外部加壓設備故價格最低，而靜壓軸承除需要供油設備等週邊設備外，軸承配合處需要使用超精密加工，故價格自然高於滾動軸承。

在德國漢諾威 EMO 展覽會場上，設計或生產動靜壓主軸或靜壓滑軌之主要廠商及其產品如下：

1.德國 SPL 主軸公司

該公司主要生產液動靜壓主軸，它們所生產的靜壓主軸稱為 ZOLLERN 靜壓主軸，具有自動間隙補償(即回饋補償)之節流特點，即在主軸油室內加入補償器，故不需人為之調整或節流器。目前總廠所進行之次微米磨床，所採用之主軸規格中，尚未採用具有自動回饋補償之功能，故必須要使用節流器來調整壓力，SPL 公司靜壓主軸之優點，可以提供總廠下階段產品發展精進之參考。SPL 公司之軸承自動補償器具有下列特點：

・最高之加工精度。
・可達最高之剛性和衰減性。
・最高之轉速。
・設計緊密。
・摩擦功率損失小。
・不管軸速如何，性能永保最佳。
・無擾流、運轉平順。
・壽命無限長。

因此使用 SPL 公司之液靜壓主軸，可得到最佳之加工品質與生產效率。該公司在靜動壓主軸方面之產品有：

(1)靜壓主軸

如圖 1 所示之主軸，為具有液靜壓徑向軸承及液動壓止推軸承之複合軸承。

(2)液動壓磨床主軸

如圖 2 所示為使用液動壓之磨床 MGF 軸承，可得到高之加工精度，其主軸偏轉度≦1 μm。

(3)液動壓精搪主軸

如圖 3(a)(b)為具有液動壓之精搪主軸，可得到高的加工精度，其主軸偏轉度≦1 μm。

2.德國 HYPROSTATIK 公司

該公司為專業的液靜壓主軸、液靜壓滑軌、液靜壓導螺桿及 PM 節流器之設計公司，主要業務為替顧客設計液靜壓零組件。經該公司設計完成且目前在運轉中之液靜壓元件，估計已超過 5000 件以上，該公司是目前世界上唯一專業替顧客設計靜壓主軸、滑軌與導螺桿的公司。

因在出國前已在網路上對該公司有所了解，且該公司在 EMO 展覽會場上也設有攤位，因此花了很長的時間與負責人討論有關液靜壓元件之設計要點、技巧，技術合作之可行性，並攜回多份有關液靜壓元件設計之技術資料，對往後次微米磨床，在液靜壓主軸及滑軌之設計助益頗多。

公差回國後仍持續透過代理商與該公司保持聯絡，希望在九十一年度能與該公司建立技術合作關係，導入液靜壓零組件設計之新觀念與技術茲將該公司較特殊之產品敘述於後。

(1)液靜壓導螺桿(Hydrostatic Leadscrew)

該公司可依顧客需求之負荷與剛性，設計直徑 40-160mm 之導螺桿，可設計成主軸或螺帽回轉型式，供油壓力範圍在 25-100bar 之間，螺紋數目範圍在 1～5 圈，導螺桿之規格如表 2 所示，其外觀如圖 4 所示。

表 2 液靜壓導螺桿之尺寸諸元

Case length[mm]	110				130
Nummer of turn each nut [left/right]	1/1	2/2	3/3	4/4	5/5
25bar	1250N 160N/μm	2500N 320N/μm	3750N 480N/μm		
32bar	1600N 200N/μm	3200N 400N/μm	4800N 600N/μm	6400N 800N/μm	
40bar	2000N 250N/μm	4000N 500N/μm	6000N 750N/μm	8000N 1000N/μm	1000N 1250N/μm
50bar	2500N 320N/μm	5000N 630N/μm	7500N 950N/μm	10000N 1260N/μm	12500N 1600N/μm
63bar		6400N 800N/μm	9600N 1200N/μm	10000N 1260N/μm	12500N 1600N/μm
80bar			12000N 1500N/μm	16000N 2000N/μm	20000N 2500N/μm

液靜壓導螺桿與傳統導螺桿比較其優點為：

- 在低速時無摩擦。
- 在微量運動時精度佳。
- 倒轉時無背隙。
- 消除顫動。
- 對污染不敏感。
- 無磨耗，在全負荷時，仍能維持精度。
- 沒有摩擦力之波動。
- 吸振性佳，改進表面光度與刀具壽命。

(2) PM 節流器(PM-Flow controller)

PM 節流器之功能為將泵送出之潤滑油，分送到靜壓導軌與主軸之油室，並且依照油室壓力來調節流量，在增加負荷之油室增加流量，而在卸載之油室減少流量，因此可使系統之剛性提高、能源消耗降低、主軸產生之熱量較少，PM 節流器之外觀及作動原理如圖 5 所示。

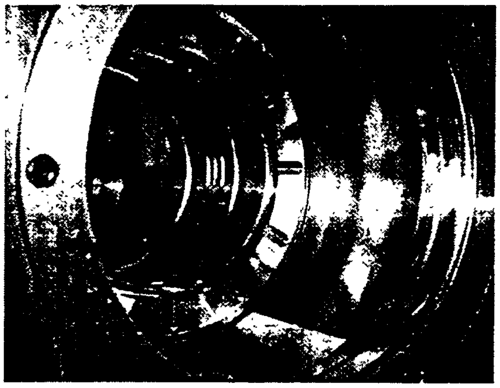


圖 1.液靜動壓主軸

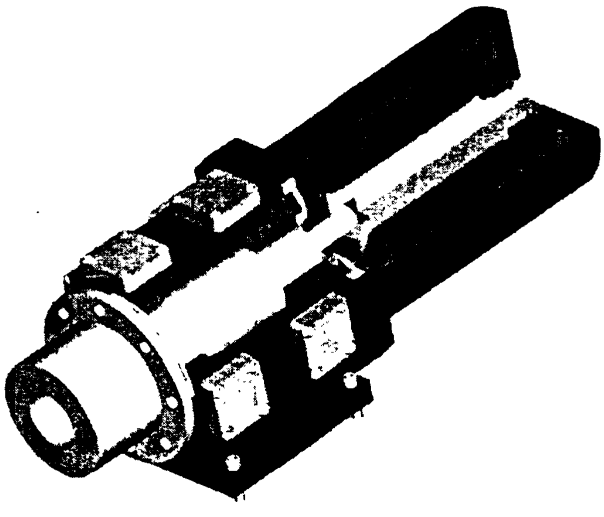
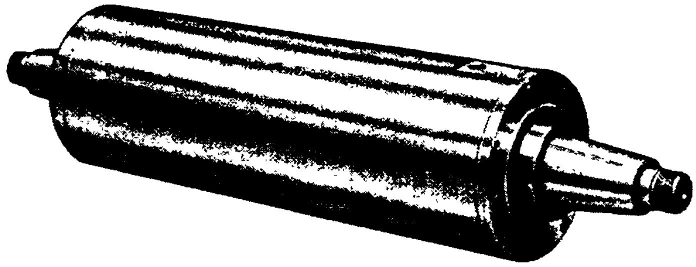
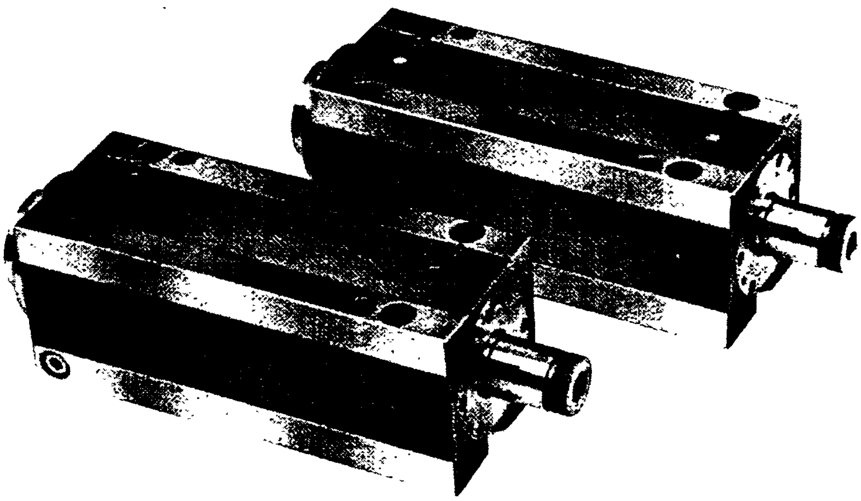


圖 2. 液動壓磨床主軸



(a)



(b)

圖 3.液動壓精搪主軸

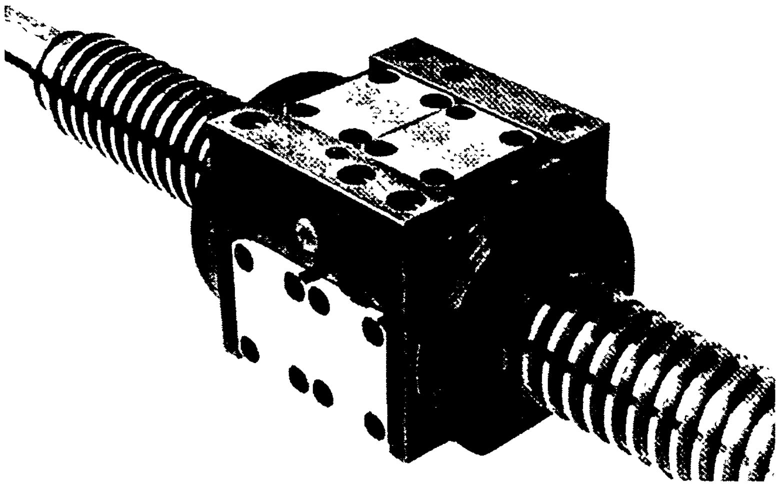
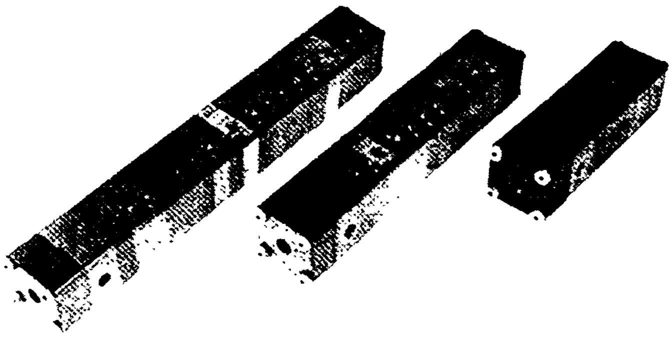


圖 4.液靜壓導螺桿



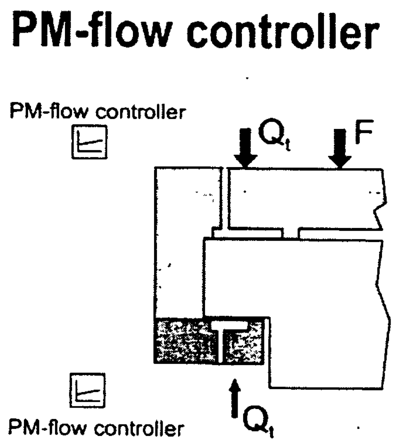


圖 5. PM 節流器之外觀與作動原理圖

(二)線性馬達與控制器

就本次2001年EMO展覽而言，仍然以高速高精度高效率加工為基本主題。利用高速進給之大導程滾珠導螺桿或直接驅動之線性馬達，搭配高速主軸，達到快速的工件移除率。除此之外，最受矚目的是各工具機廠開發的網路連結技術。以下針對這次展覽會的最具特色的展示動向敘述如下:

1.線性馬達之優點

配合世界工具機發展的趨勢，發展快速、精密之加工機，研製高速主軸以增加主軸轉速，由原先之3000~6000rpm之轉速增至20000 rpm以上，水平運動之驅動機構則由原旋轉馬達帶動滾珠螺桿之方式，改為由線性馬達直接驅動之方式，使用線性馬達具有以下的優點:

(1)線性馬達為直接驅動之致動器。
(2)使用線性馬達可省去機械傳動件，故可增加剛性(不用滾珠導螺桿，不受限材料之彈性係數)、無背隙、無磨耗、允許多個動子在同一滑軌上、允許無限長之行程，而不失其位置精度。
(3)使用線性馬達是為了提高系統的動態響應 (High Dynamics)，即達到高伺服剛性(抗干擾性)、高速、高加速度及頻寬、高定位精度及較低之速度漣波及較小之安定時間。故系統需滿足高解碼精度及頻寬，為了得到良好的的速度控制性能，速度回路之頻寬須大於位置回路頻寬之 10 倍，位置解析度為 0.1micron 或更小，高的位置回路頻寬(100-250Hz)，動態剛度在 300-700 N/micron (1.7-4.0 Mlbs/inch)之範圍，電流回路及位置回路具高取樣率 (對於大部份旋轉馬達1-2 KHz之曲樣率可被接受，而對於線性馬達需高於此5-10倍)。
(4)省去機械傳動元件之利弊，利益在於直接驅動之線性馬達具高速動態響應，不再受限於背隙、柔順性(Compliance)、速度及磨耗等問題。缺點則是切削力、磨擦力、機台慣性力等外力直接加於線性馬達上;因此控制器必須即時的對這些外力進行補償，增加了控制的困難性。而且馬達產生的熱直接傳至負載。

對於高性能之線性馬達須具備以下幾種條件:第一、高速動態響應。第二、低熱量產生。第三、高性能之驅動器及控制器。第四、高機械剛度。對於精密控制用之線性馬達為直接驅動且無框架,採用永久磁鐵設計設計,以提供高速動態特性(剛度及加速度)及低熱量產生,有兩種架構一種為鐵心式、另一種為無心式,無心式線性馬達之特性為:

- 雙側永久磁鐵架構,每一側之間隙約 0.5 mm。
- 無鐵心之設計方式提供零鈍動(Zero Cogging)。
- 移動線圈與磁鐵間無吸力。
- 線圈設計提供很高的馬達常數。
- 移動線圈質量輕,可獲得高加速性。

無心式線性馬達之應用領域為所有半導體製程設備、插件機、座標量床及任何需要線性運動且輕負荷之應用場合。

本次展覽中,大部份工具機所使用的線性馬達為有心式線性馬達其特性為:

- 單側式永久磁鐵設計,氣隙約 1mm。
- 單位長度之輸出力約為無心式線性馬達的三倍。
- 最大出力達 10000N。
- 較高之熱時間常數。
- 屬於專利之線圈設計提供非常高的馬達常數 K_m。
- 屬於專利之低鈍動力,磁鐵不必傾斜擺置。
- 單位尺寸獲得最大之連續推力。
- 馬達可加氣冷或水冷。
- 模組化磁鐵座容易組合,行程無限。
- 永久磁鐵鋪成的軌道上可加裝多個動子。
- 電磁鐵與永久磁鐵間所產生之吸力約為推力之 10 倍。

鐵心式線性馬達應用場合為高速工具機的應用、雷射及水刀切割機、紡織機械、物料搬運及任何需要線性運動且重負荷之應用場合。無論是無心式或鐵心式線性馬達,線圈長度愈長或寬度愈寬所產生之推力愈大。

2.線性馬達在工具機上之應用

本次展覽各家廠商所推出的產品都是以「高生產性」為前提，其中最受矚目的焦點是從超高速、高精度、複合化技術至資訊技術的活用及網路的連結。首先針對主軸搭配線性馬達進給機構，在超高速切削工具機方面的應用工具機會場中以德國 Deckel Maho 公司最為搶眼，所推出之工具機皆為線性馬達驅動之工具機，此型工具機具有極佳的動態性能及高進給力，以提升機台的精度及切削速度其特點為:

第一，為數位化的線性馬達模組，提供高達 2G 的加速度，快速的移動速度高達 120m/min 。第二，在於工具機的結構，門型的機台結構上，安裝三個軸向的線性馬達，大型的單體床台設計 (Bed in Mono-block design)， 具吸振能力並防止機台變形，以獲得最佳的加工精度、快速的材料移除率及較長的刀具壽命。

主軸技術亦為另一項設計的重點，由於採用陶瓷滾珠軸承，五軸加工機主軸馬達振動量極低、精密度高、剛性高、主軸壽命長、且溫度穩定。

搭配西門子 840D 數位 CNC 與數位伺服驅動器，提供極為精密的五軸循軌功能，並結合創新的結構設計，使工具機具有高動態剛性，並獲得超快的移除率，這些重點為高性能加工機的關鍵因素。

Deckel 另一型銑床 DMP 60 linear，亦採用線性馬達。切削加速度高達 1.5G，此型工具機具有如下之創意: X，Y，Z 三軸為線性馬達驅動，以獲得高速的動態性能及精度，並增加產能。搭配堅實的 2 軸 CNC 搖動/旋轉式工作台 (NC swivel rotary table) 及交換系統 (Pallet changing system)，可進行 5 面加工，並達到 5 軸同動的功能，有效的增加產品的品質。特別的 45 度傾斜式床台設計，提供高剛性及切削時的抗振能力。先進的工作台換置機構設計(Changer)，容許加工中進行下一工件的前置作業以減少機器的停頓 (Idle) 時間。

此外，Sodick 公司推出搭載線性馬達的放電加工機「AQ35L」機型。透過線性馬達的高速追蹤能力，幾乎所有的加工時間都縮

短為傳統旋轉馬達驅動放電加工機的一半，另外 Sodick 亦推出搭載線性馬達的線切割機「AQ55L」機型，實現高精度加工。

3.線性馬達的數值控制器

數位化電腦數值控制器 (CNC , Computer numerical control) 能夠增加產量及降低成本。今日，所有工具機製造廠，它們常面對的一個問題是，到底什麼樣規格的工具機才算是一部高性能的 CNC 工具機，答案即是驅動工具機之控制器，事實上控制器決定了工具機的性能及價值。

此次展覽會，由德國西門子所推出的 Sinumerik 840D 控制器，即被用於線性馬達工具機台上，此型控制器為 PC based，屬於開放式架構 (Open-architecture) 之 CNC，具有如下之標準功能: 內建五軸座標轉換、平滑之加減速運動、直接曲線補間 (Direct Nurbs interpolation) 功能、可使用高階語言、可執行大容量的 CNC 程式、100 組的 zero offset、適應性控制、刀具磨耗補償功能、機器動態可程式化。 Sinumerik 840D 控制器之通用軟體，可廣泛用於鑽、車、銑、磨加工上，由於是開放式架構，也適合於衝孔及雷射切割的應用上。Sinumerik 840D 可同時控制 31 個驅動模組。

高性能之線性馬達需要有高性能之驅動器及控制器，為了達到高速動態特性驅動器應考慮:

- 為了獲得穩定性、剛度及抗干擾力，電流及速度回路頻寬需高，線性馬達系統回路的頻寬需高於旋轉馬達系統頻寬的 3-5 倍。
- 對於固定之 BUS 電壓，在大的速度範圍下可獲得固定的推力。
- 全數位化的驅動器，可調整控制參數，直接驅動之線性馬達裝於機台上需要適當的調整控制器參數以獲得良好的性能。
- 使用高階之運動控制法則(Advanced Pole Placement)以補償結構之共振。
- 光學尺回授元件至驅動器之輸入頻率至少 2.5MHz。
- 在低速時，驅動器將光學尺回授之低頻訊號，進行正弦插值(Interpolation)計算，以獲得高定位及速度精度。
- 為了安全起見，必須具煞車功能。

觀察這次展覽的線性馬達工具機，伺服驅動器已都具備如下的性能:

- 全數位、三相、正弦波驅動之伺服放大器。
- 可達 3-55Amp、170-330 Volts 之輸出。
- 高階之運動控制法則。
- 可控制出力角度 660 Volts 之大推力線性馬達。
- 增加電流及速度回路之頻寬。
- Sercos 數位界面。
- 光學尺輸入頻率高達 2.5MHz。
- 具正弦插值功能。
- 訊號失誤時可進行動態煞車。

4.線性馬達的組裝

經與多家參展廠商技術人員討論，使用及組裝線性馬達需注意的事項及考慮重點整理如下:

- 欲達高速動態性能，機械結構之剛性必須加強。
- 傳統滾珠導螺桿驅動之機械結構，不再能適用於線性馬達驅動之機械結構，必須重新設計，線性馬達之移動部需接近機台之重心軸，以防止產生扭矩及振動。
- 鐵心式線性馬達除提供推力外，亦提供正向吸力，此吸力可提供線性滑軌預壓之用，但組裝時需小心。
- 線性滑軌需能抵抗最大吸力(約最大推力之 5 倍)，並與供應商確認線性滑軌可容許之最大速度與加速度。
- 若最大推力超出型錄可提供之推力時，可將幾組馬達並排組裝。
- 可使用兩組磁鐵及兩組線圈並作背對背之排列方式，以抵銷馬達正向吸力。
- 在動子線圈運動所及之行程內，線圈及霍耳感測器下須鋪有磁鐵。
- 氣壓軸承僅適用於無心式線性馬達，對於鐵心式之線性馬達因具大的正向吸力，且最大電流 (Peak Current +/-20%) 的變化將使得空氣軸承產生不穩定現象，故不建議採用。
- 線性馬達之選擇應考慮馬達尺寸、伺服放大器、光學尺解碼、系統及機械問題。
- 決定馬達尺寸之因素: 確定運動軌跡、外力、外力是否隨速度

變化、外力是否隨位置及方向變化。外力有磨擦力 (磨擦係數一般為 0.002-0.005) 、重力、阻尼力、彈簧力及慣性力。

- 運動軌跡: 確認正反位移方向之速度對時間之曲線圖，使用梯形速度曲線圖，在所有運動軌跡上加速度應保持一致。
- 使用線性馬達應考慮負載是否為固定或者隨位置變化。
- 考慮馬達長度或寬度之限制。
- 考慮氣冷或水冷。
- 考慮馬達容許最高溫升。
- 考慮電源供應 (AC 輸入電壓或 BUS 電壓)之選擇。
- 考慮機械結構，能否抵抗吸力應予考慮。
- 依據溫升、Bus 電壓、最大推力、均方值推力及最大尺寸及不同之繞線方式選用適合的線性馬達。

二、參訪 SANDVIK 刀具廠心得

此次出國的任務之一，是將本廠在加工 Ti-6Al-4V 鈦合金與鎳基超合金 INCONEL 718 所遇到之技術瓶頸，希望透過與原廠技術人員之討論與現場示範，尋求最佳之切削刀具與參數，因此在出國之前，即透過 SANDVIK 公司在台灣之代理商與原廠交涉，將本廠目前遭遇之問題，希望原廠安排專業工程師與我們進行研討，並至現場參觀實際加工示範，而原廠也欣然答應，在 9 月 10 日當天安排一整天之研討與示範，茲將當天研討的主題與心得敘述於後。

(一)Ti-6Al-4V 鈦合金之切削加工

Ti-6Al-4V 鈦合金有下述之特點：

- 比強度高。
- 抗腐蝕性。
- 熱傳導係數低。
- 在高溫時活性強。
- 彈性模數低。

所以在加工切削時容易產生刀具磨耗，此磨耗主要與材料的化學活性、磨耗特性、及熱傳導性有關。本廠在進行劍二 MER-288 彈射架車、銑、鑽削加工過程中，使用 SANDVIK 刀具廠所提供之刀片，材質分別為 H13A 及以 TiCN 被覆的 GC1020，並依原廠所提供之切削參數進行加工，主要的參數如下分別如下：

切削速度 V(m/min)：40-90
轉數　　N(rev/min)：636-1432
進給　　F(mm/rev)：0.05-0.12

結果發現使用未被覆之 H13A 刀片鉆削 27 孔後鉆頭已磨損嚴重；而使用以 TiCN 被覆之 GC 1020 刀片，鉆削 30 孔後磨損比 H13A 刀片更嚴重。由此可知以上述二種材質之刀片鉆削 Ti-6Al-4V 鈦合金均未能達到合理之壽命，鉆頭磨損迅速。在原廠與切削工程師研討結果，他們建議鈦合金切削之基本原則為：

- 切削速度要低。
- 使用切削液。

・使用銳利之刀具。
・切削中途不可停止進給。
・刀具與工件組裝要堅固。

而他們建議之鉆削刀具與參數如下表 3 所示

表 3.Ti6Al-4V 鈦合金之最佳加工參數

刀具種類	切削速度 V（m/min）	進給 F(mm/rev)
U-drill C＝-53 H13A P＝-58H13A	100	0.08
Pelta-C 1020 30-40bar Max 0.02mmT.I.R	40	0.12

經過現場切削示範，以上述條件切削鈦合金，不但刀具壽命可提高至合理範圍，同時鉆孔之表面光度佳，品質達到藍圖之要求。除了鉆削外，原廠同時也提供了銑削、開槽、外形加工，槽孔加工等各種鈦合金加工，最佳之切削刀具與參數供本廠參考。

(二)鎳基超合金 INCONEL 718 之切削加工

超合金 INCONEL 718 目前應用在雄三與擎天計畫之燃燒室，屬於耐熱鎳基超合金，不管是在固溶或時效狀態下均不易加工，本廠以擎天整流板做車削試驗，使用原廠推薦之切削參數，如表 4 所示。

表 4.INCONEL 718 車削加工原廠推薦之參數

刀片種類	切削速度 V(m/min)	進給 F(mm/rev)
1005	40-60	0.15-0.20
H10A	40	0.35
H13A	20	0.20

經與 SANDVIK 工程師討論結果發現，INCONEL 718 與 WASPALLOY 兩種鎳基超合金，若使用 1005 刀具，切削速度 V 在 40-60m/min 間時，會造成工件之材料在刀具上產生被覆，刀腹被覆工件材料後會造成刀具壽命降低。

若將切削速度提高至 60-80m/min，雖然刀腹仍會因被覆工件材料而磨損，但是情況較切削速度 40-60m/min 時輕微，當切削速度增加至 90m/min 時，由於高溫會造成刀腹迅速磨耗、塑性變形及刀具在切深線上產生凹口，故使用 1005 刀片最佳之工作區域是在切削速度 60-80m/min 之間。

若選用 S05F 刀片來加工 INCONEL 718(硬度 HRC 46)，則可得到非常好之加工效果，選用此刀具時，切削速度之選擇建議依據 SCL(spiral cutting length)來選擇因為：

・S05F 刀具有可預測之刀具壽命特性。
・每一個特性點必須在工件上經過不同之接觸時間。
・在已知直徑上加工一段距離之接觸時間依 feed/rev 而定。
・使用 S05F 刀片，建議先計算總切削長度，然後再選用對等之速度，以達到最大之生產率
・進給率(F)會影響 SCL，但不會影響某一固定磨耗標準所能達到之接觸時間。

例如使用 S05F 刀片，以 F＝0.25mm/rev 之進給，切削長度為 590mm 時之 SCL=682m；但使用 F＝0.15mm/rev 之進給，其它參數均相同之情況下其 SCL＝1136m，使用 S05F 刀片加工 INCONEL 718，建議採用之切削參數如表 5 所示。

表 5.INCONEL 718 使用 S05F 刀片之車削參數

	Feed 0.15mm/min		Feed 0.25mm/min	
V	mins	Cutting length	mins	Cutting length
40	38	1520	38	1520
60	18	1080	18	1080
80	11	880	11	880
100	6	600	6	600
120	3	360	4	480

參、效益分析

綜觀此次參訪，所獲效益分析如下：

1.瞭解國外液靜壓主軸及滑軌最新發展趨勢，與應用在工具機業之現況，有助於執行中之次微米磨床計畫，關鍵技術之掌握與規格訂定。

2.瞭解先進國家線性馬達發展的現況及方向，提供未來計畫執行的參考。

3.瞭解國外工具機驅動系統規格，有助於未來科專建案之參考及確立發展目標與方向。

4.經由技術討論，針對線性馬達應用於工具機驅動系統，所應考慮及注意事項，與週邊元件的匹配性有所瞭解。

5.對於驅動器控制方式進行討論，瞭解國外目前驅動器內部控制法則之操作模式，及全數位化控制理念。

6.學習線性馬達為驅動模組之工具機傳動技術，提升線性馬達研製技術能量。

7.對超合金、鈦合金等難削材之切削加工，獲得如何選用最佳切削刀具與參數之技術資料，有效解決本院各型飛彈加工製造之技術瓶頸。

8.了解國外工具機及其關鍵技術之最新發展趨勢，有助於規畫軍通計畫中次世代工具機之研發策略及技術規格之訂定。

肆、國外工作日程表

本次出國起訖日期為90年09月08日至90年09月17日，包括去程與回程共10天，國外工作日程表如下。

項次	日期	地點	交往接觸人士及機關（外文名及譯名）				洽談內容紀要
			姓名	國籍	性別	地址	
1.	9/10	瑞典 SANDVIK 公司	Bengt-Olsson Jonas-Wiklund Mikael-Lovblad	瑞典	男 男 男	SE-81181 Sandviken Sweden	•討論超合金及鈦合金等難削材之切削刀具與參數選用，並參觀現場實做。
2.	9/11	德國 ZEISS 公司	Heinz-Gundlach	德國	男	Unternehmen Sbereich Industrielle Messtechnik D-73446 O berkochen	•討論精密光學量測儀器及鏡片之製程，並至現場參觀生產線。
3.	9/12	德國 INGERSOL 公司	Karl-Heinz	德國	男	Werkzeugmas Chinen GMBH D-57299 Burbach	•介紹各種工具機之設計製造、組裝及生產資源整合情形，並參觀現場。
	9/12	德國 SCHULER 公司	Fabio-Corbetta	德國	男	Louis-Schulerstras -scz D-57234 Wilnsdorf	•介紹使用液壓成型各種汽車及航太零組件，並至現場參觀加工流程。
4	9/13 ≀ 9/15	德國 漢諾威2001年 EMO 工具機展	Jochen-Schonfeld Marco-Kaufmann	德國	男 男	Gewerbegebiet Stauferpark D-73037 Goppingen CH-6330 Cham-Switzland	•參觀液靜壓主軸及滑軌在各型工具機上之應用。 •參觀線性馬達在次世代工具機上之應用。

伍、社交活動

本次總廠三名人員前往瑞典、德國參訪，是參加由台灣區模具同業公會所籌辦的〝2001 年德國工具機大展暨工廠參觀見學考察團〞，因此除在瑞典拜會 SANDVIK 刀具廠時，本院的人員與考察團暫時分開行動外，其餘所有行程都是整團集體行動；因此在參觀工廠時，均由團長代表全體團員與各工廠之接待人員致意，其餘團員很少有機會直接與參觀工廠之人員交流。因此大部份之社交活動，都侷限在團員之間彼此的參觀心得交流。茲將本次出國在行程中之社交活動分述於後。

(一)與 SANDVIK 刀具廠人員之社交活動

因為我們是單獨拜會 SANDVIK 刀具廠，該廠指派產品工程師 Bengt Olsson 接待我們，在歡迎晚餐會上，同時為我們介紹次日之行程，討論與示範的主題有：

1.Aerospace segment-Frame titanium 6Al4V milling demo
2.Solid Carbide tools
3.Turn-Mill demo in productivity center
4.Aerospace segment-Gas Turbine Inconel 718 turning demo
5.Lunch at the company restaurant
6.Ceramics in heat resistant superalloys
7.Summing up

上述課程之講授與示範人員包括：
Bengt Olsson-product Engineer, Turning Grades
Jonas Wiklund-product Engineer, Advanced Materials Mikael Lovblad-product Engineer, Solid Carbide Tools Thomas Lundmark-Manager, Aerospace Frame Segment

當天主要與該公司之各部門工程師及技術人員討論如何選用 Ti-6Al-4V 鈦合金與 INCONEL 718 超合金之加工刀具與切削參數之選擇，同時針對本廠所做之切削試驗數據，請該廠人員指正問題之所在，並提供正確之測試及量測方法，SANDVIK 廠並將討論之綱要與結果，做成技術報告送給我們，做為難削材加工刀具及參數選用之指南。

(二)德國參觀工廠之社交活動

在德國參觀 ZEISS 公司、INGERSOL 公司，SCHULER 公司，均由模具同業公會負責人辛培舜先生、團長中正大學機械系主任陳政雄先生，代表考察團致歡迎詞與致贈紀念品，在參觀 INGERSOL 公司時，該公司之台灣代理商黃萬鐘先生全程陪同，中午接受該公司軋輥加工設備部主任 Karl-Heine Heberer 之午餐款待。

(三)參觀漢諾威 EMO 展之社交活動

參觀 EMO 展的三天，每一個人都將精力專注於尋找自己之所需要之資料，所有的時間都花在與廠商間之研討與資料蒐集，這段期間內與幾位廠商代表有較深入之討論與接觸。

1.Hyprostatik 公司之負責人 Jochen Schonfeld，與他討論有關液靜壓主軸滑軌之設計與 DM 節流器技術移轉之可行性。

2.與 HMP 公司之主任 Elmar Dischel、M&M 公司之經理 Marco Kaufmann、LEICO 公司之經理 Lothar Heiringhoff、LEIFELD 公司之專案工程師 Gregor Pospiech 等 4 位，討論旋壓成形之技術與機器規格，因本廠之旋形機採購已十餘年，目前面臨維修問題，上述 4 家公司均有生產流旋形加工機，故與相關人員討論旋形機之規格功能與採購及輸出許可等問題。

陸、建議事項

本次參加台灣區模具工會舉辦的〝2001 年德國工具機大展暨工廠參觀見學考察團〞，總廠在 6 月中旬即接到模具工會之邀請函，之後就積極辦理公差出國事宜，期間承各級長官之協助，在 8 月下旬即辦妥出國手續。在這二個多月之時間，公差人員就自己希望在展覽會場上蒐集的資料，或研討的廠商，分別透過國內代理商或經由網路與國外廠商取得連繫，因此在公差期間，各人均能依預先期望滿載而歸，對日後主計畫工作之推展與軍通計畫之執行，奠定了成功之基礎。但在辦理公差出國之手續與廠商接觸時，仍發現有一些仍值得我們借鏡之處，謹提出來供參考。

1. 與考察團同行出國公差，因民間公司彈性較大，對不預期之更改時程與旅程，應變彈性較大；相較之下，本院有規定之作業時程與流程，無法配合臨時更改之時程。建議在不更改公差天數與經費原則下，若配合考察團之行程而更改旅程，只要取得考察團之證明，回國後再報備即可。
2. 在拜會 SANDVIK 刀具公司期間，雖然本院僅三人前往，但該公司仍安排一個正式之研討會，並派 7 名工程師與我們討論，可見他們對顧客服務之誠意，不會因人數少或層級低而敷衍了事，這點在對本院來說，確是一個絕佳之學習機會，尤其正值本院要走出去與民間公司技術交流時，顧客第一，服務至上之信念一定要劍及履及。
3. 軍民通用科技計畫之執行，牽涉到很多關鍵技術，其中有的是本院已經建立的，但大部份是必須新開發的技術，為有效執行計畫，在國外已經公開的關鍵技術，建議採取技術合作方式，直接引進關鍵技術，以有效縮短研製期程。

附件

附件一、液靜壓主軸設計(SPL 公司技術報告)

附件二、液靜壓導螺桿設計技術資料(Hyprostatik 技術資料)

附件三、液靜壓主軸設計技術資料(Hyprostatik 技術資料)

附件四、鈦合金加工刀具與參數選用(SANDVIK 測試報告)

附件五、超合金加工刀具與參數選用(SANDVIK 測試報告)

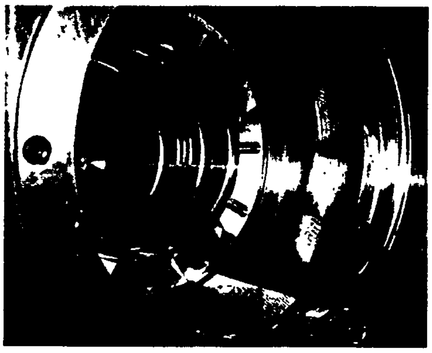
附件一、液靜壓主軸設計
(SPL 公司技術報告)

HYDROSTATISCHE SPINDELN

Hydrostatic Spindles

SPL fertigt Spindelsysteme mit hydrostatischer und hydrodynamischer Lagerung sowie mit Wälzlagern. Unsere Erfahrungen mit diesen unterschiedlichen Systemen ermöglichen es uns, optimale kundenspezifische Spindelsysteme anzubieten.

SPL manufactures spindle systems which utilize hydrostatic, hydrodynamic and rolling element bearings. Our experience with these different concepts enables us to provide optimal customized spindle systems.



Sonderlager mit hydrostatischem Radial- und hydrodynamischem Axialteil

Special bearing with hydrostatic journal and hydrodynamic thrust

Die Vorteile hydrostatischer Spindeln sind:

- höchste Arbeitsgenauigkeit
- hohe Steifigkeit und Dämpfung
- hohe Drehzahl
- kompakte Bauweise
- Verschleißfreiheit

SPL verwendet vorzugsweise hydrostatische Lagersysteme von ZOLLERN. Die präzise Lagerung, bei einer wesentlichen Steigerung der Umfangsgeschwindigkeit, ist auf eine Entwicklung eines laminaren Vordrosselsystemes, der ZOLLERN Laufspaltdrossel, zurückzuführen.

Besondere Merkmale sind:

- höchste Dämpfung durch spezielle Gestaltung der Lagertaschen
- Verwendung von niederviskosen Ölen
- konstante Taschendrücke über dem Drehzahlbereich durch isoviskoses Verhalten des Drosselsystemes
- turbulenzsicheres und laufspaltunempfindliches Drosselsystem

SPL Hydrostatikspindeln erreichen höchste Bearbeitungsqualitäten bei absoluter Wirtschaftlichkeit.

The advantages of hydrostatic spindles are:

- highest machining accuracy
- high stiffness and damping
- high shaft speeds
- compact design
- virtually unlimited bearing life

SPL uses the ZOLLERN hydrostatic bearing system with automatic clearence compensation. SPL spindles incorporate the compensator within the hydrostatic bearing pocket. This requires no manual adjustment or throttling devices.

Advantages of automatic bearing clearence compensation are:

- highest possible stiffness and damping
- low power loss due to the use of low viscosity oils
- consistent optimum performance independent of shaft speed (iso-viscous)
- turbulence free, smooth operation

SPL Hydrostatic Spindle Systems produce excellent machining quality and production efficiency leading to high profitability.

SPL Spindel und
Präzisionslager GmbH

GLEITGELAGERTE SPINDELN

Hydrodynamic and Hydrostatic Spindles

Hydrodynamik-Feinbearbeitungsspindeln mit Mehrgleitflächenlagern (MGF) zeichnen sich durch hohe Bearbeitungsgüte und Rentabilität aus.

Hydrodynamic and hydrostatic fine-machining spindles with multi-lobe bearings – known by their German acronym, MGF – feature excellent machining quality and production efficiency, which translate to high profitability.

Auf dem Gebiet der Oberflächenfeinstbearbeitung gewährleisten diese Spindeln beste Oberflächengüten.

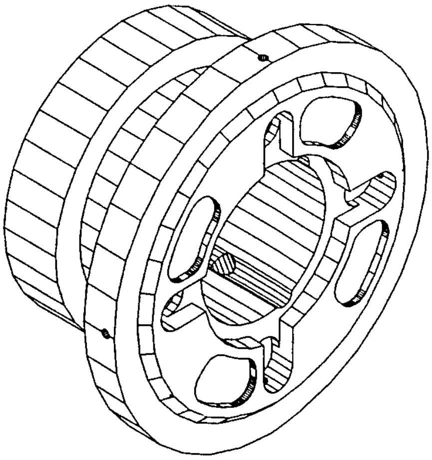
For precision surface machining, these spindles guarantee the best quality finish you can find.

Konstruktiv zeichnen sich MGF-Spindeln durch ein stabiles Gehäuse mit steifer Welle aus. Die äußere Form kann an vorhandene Maschinenkonstruktionen angepaßt werden.

The distinguishing feature of the design of MGF spindles is their rugged housing that contains a stiff shaft. Their external shape can be adapted to fit existing machine designs and configurations.

In SPL-Spindeln werden hauptsächlich Mehrgleitflächenlager eingesetzt. Deren unrunde Lagerbohrung besteht aus fest eingearbeiteten Gleitflächen, deren Radien exzentrisch zur Welle sind. Als Ergebnis dieser Bauform werden höchste Rundlaufgenauigkeiten und eine definierte Wellenlage erreicht.

Multi-lobe bearings are primarily used in our SPL spindles. Their non-circular profile of the bearing bore consists of several lobes permanently machined into this bore. The radii of these lobes are off-centered with respect to the spindle shaft. This design results in exceptionally good centering action on the shaft, creating extremely precise shaft rotation and a defined shaft position.



Vorteile der gleitgelagerten Spindeln

Gleitgelagerte Spindeln

- sind **kostensparend**, da die Gleitlager hohe Drehgeschwindigkeiten erlauben und sich dadurch die Bearbeitungszeiten verkürzen. Desweiteren lassen sich manche problematischen Werkstoffe überhaupt erst durch die hohen Geschwindigkeiten der gleitgelagerten Spindeln bearbeiten.
- haben eine **hohe Lebensdauer**. Diese wird bei unseren Spindeln durch eine gute Ölversorgung der Gleitlager mit dem entsprechenden Aggregat gewährleistet.
- sind **geräuscharm**, da die rotierende Welle von einem Ölfilm getragen wird.
- haben **überlegene Dämpfungseigenschaften**, da die Druckverhältnisse flächenförmig auf den Ölfilm verteilt werden und sich dadurch die Schläge und Vibrationen bzw. Schwingungen kompensieren lassen. Damit finden unsere Spindeln weitverbreiteten Einsatz in Schleifmaschinen und Prüfständen.
- gewährleisten eine **Rundlaufgenauigkeit** von unter 1 µm. Deshalb können höchste Bearbeitungsgenauigkeiten mit den Präzisionsspindeln erzielt werden.

Advantages of Hydrodynamic and Hydrostatic Spindles

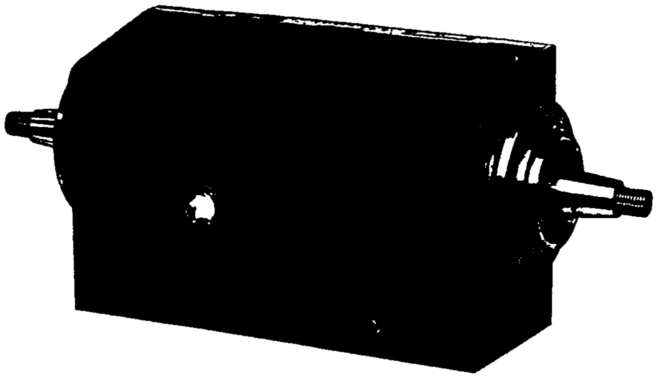
Hydrodynamic and hydrostatic spindles

- **save money** because hydrodynamic bearings allow high-speed rotation, which reduces processing time. Moreover, these high-speed hydrodynamic spindles now make it possible to machine and optimize cutting of problematic materials;
- have a **long life cycle** guaranteed by the excellent oil supply to the hydrodynamic bearings provided by our application-specific hydraulic oil packs;
- have a **low noise level** because the rotating shaft of the spindle is carried by an oil film;
- have **superior damping characteristics** because the pressure within the spindle system is distributed over planar surfaces of the oil film, thus compensating cutting forces and vibration and eliminating „chatter marks“ on workpieces. As a result, SPL spindles are widely used in grinding machines and test rigs;
- ensure a **peripheral rotation accuracy** of less than 1 µm. This is why our precision spindles achieve the highest machining accuracy.

MGF-Hydrodynamik-Anbau-Schleifspindel S

Bolt-on MGF hydrodynamic grinding spindle S

Gleitgelagerte Spindeln

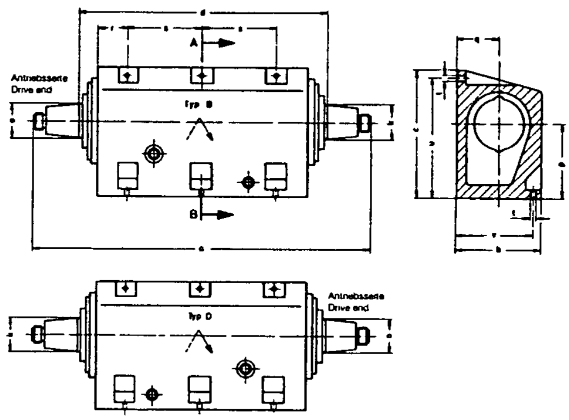


mit MGF-Lagern für hohe Arbeitsgenauigkeit
Rundlaufgenauigkeit ≦ 1µm

with MGF bearings for high working accuracy
Concentricity ≦ 1 µm

Kegel 1:5 DIN 6375
Taper 1:5 DIN 6375

Gehäuseschnitt A–B
Housing section A–B



Maße / Dimensions	Typ / Type S 105-B/D	Typ / Type S 110-B/D	Typ / Type S 125-B/D
a	900	920	980
b	230	250	270
c	280	370	400
d	620	640	700
k	100	100	100
o	100	100	100
p	140	240	255
q	115	125	133
r	–	40	40
s	–	220	250
t	18	18	18
u	–	355	378
v	210	236	250
Schmierart lubrication type	Umlaufschmierung external lubrication	Eigenschmierung self lubrication	Eigenschmierung self lubrication
Nenndrehzahl (1/min) rotation speed (rpm)	1400 1400	750 750	1200 1200

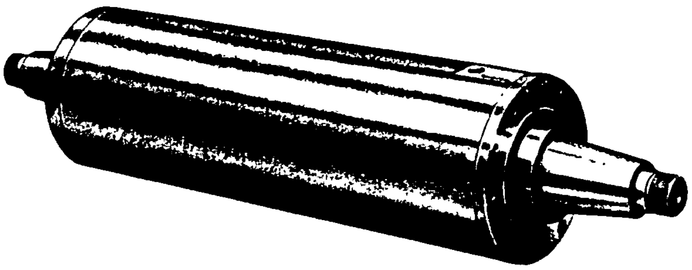
Andere Größen und Außenformen bzw. Drehzahlbereiche auf Anfrage.
Other sizes and external shapes or speed ranges on request.

SPL Spindel und
Präzisionslager GmbH

Gleitgelagerte Spindeln

MGF-Hydrodynamik-Feinbearbeitungsspindel DR

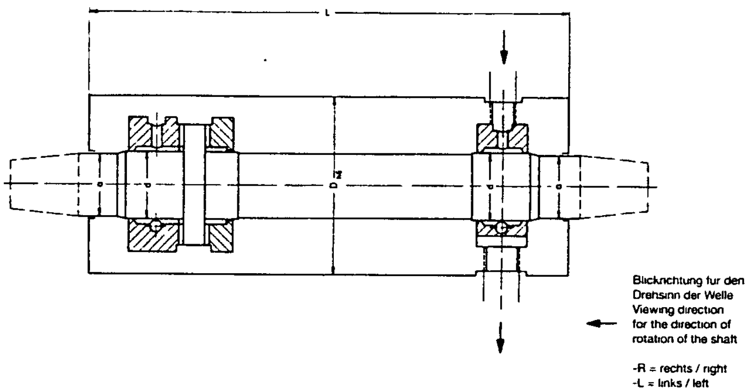
MGF hydrodynamic fine-boring spindle DR



mit MGF-Lagern für hohe Arbeitsgenauigkeit
Rundlaufgenauigkeit ≦ 1µm

with MGF bearings for high working accuracy
Concentricity ≦ 1 µm

Schmierart:
Fremdschmierung
Lubrication type:
external lubrication



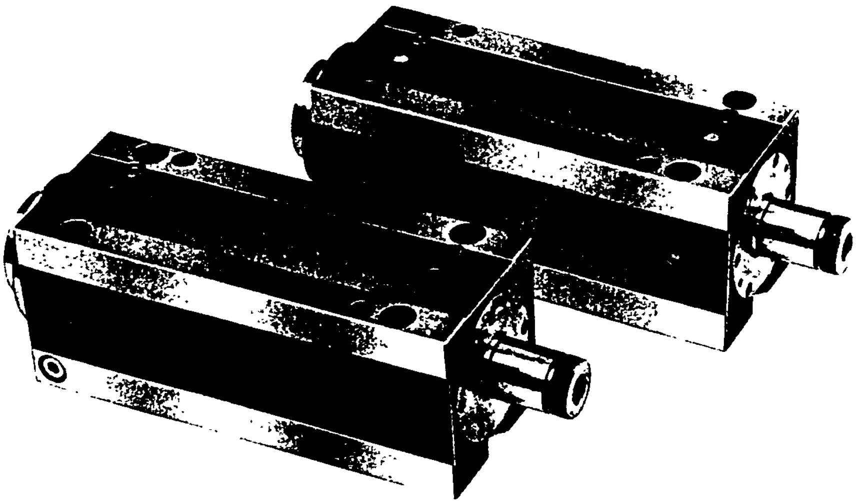
Kurzzeichen / Reference	D_{h6}	L	a	d
DR 60	60	150	18	20
DR 80	80	200	28	30
DR 90	90	250	32	35
DR 100	100	250	35	40
DR 110	110	300	45	50
DR 120	120	350	50	55
DR 140	140	400	60	65
DR 150	150	400	65	70
DR 160	160	450	70	75
DR 180	180	500	85	90
DR 200	200	550	95	100

Die Wellenenden werden nach gewünschten Anschlußmaßen gefertigt. Andere Größen auf Anfrage.
The shaft ends are manufactured to specifications. Other sizes on request.

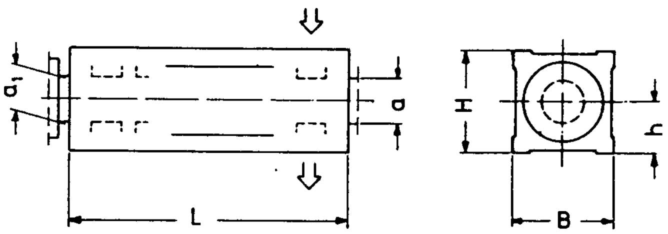
SPL Spindel und
Präzisionslager GmbH

MGF-Hydrodynamik-Feinbearbeitungsspindel AF

MGF hydrodynamic fine-boring spindle AF



Ausführung mit ZYBLO Lagern (spieleinstellbar) auf Anfrage.
Design with ZYBLO bearings (clearance adjustible) on request.



Kurzzeichen Reference number	B	L	H	h	a_1	a	n = (1/min) n = (rpm)
AF 117	117	395	155	80	60	42	2500
AF 152	152	450	162	101	62	45	6000
AF 150	150	395	155	80	70	54	5000
AF 170	170	395	180	95	77	54	1000
AF 315	315	568	340	200	155	110	2300

Die Wellenenden werden nach gewünschten Anschlußmaßen gefertigt.
Andere Größen und Außenformen bzw. Drehzahlbereiche auf Anfrage.
The shaft ends are manufactured to specification.
Other sizes and external shapes or speed ranges on request.

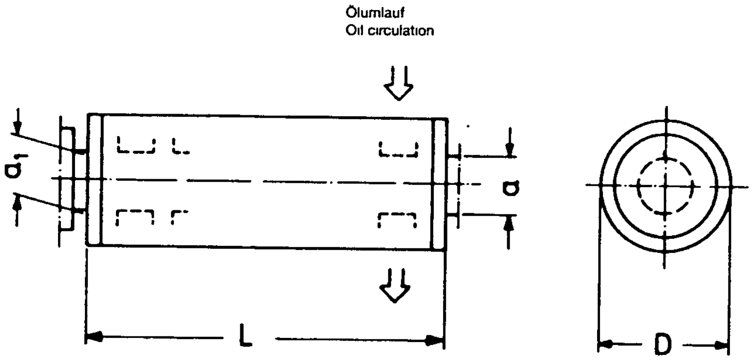
SPL Spindel und
Präzisionslager GmbH

Gleitgelagerte Spindeln

Hydrodynamik-Feinbearbeitungsspindel F

hydrodynamic fine-boring spindle F

Ausführung mit ZYBLO Lager
(spieleinstellbar)
design with ZYBLO bearing
(clearance adjustible)



Kurzzeichen Reference number	D	L	a_1	a	n = (1/min) n = (rpm)
F 60	60	202	32	23	3000
F 80	80	230	45	29	3000
F 100	100	390	55	35	4000
F 120	120	350	62	45	4000
F 125	125	414	70	50	3300

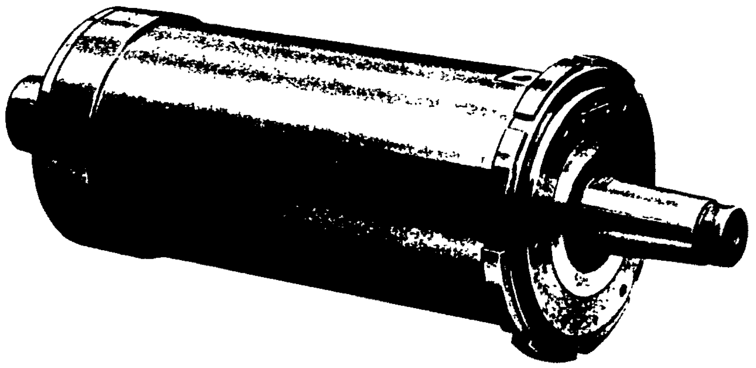
Andere Größen und Außenformen bzw. Drehzahlbereiche auf Anfrage.
Other sizes and external shapes or speed ranges on request.

SPL Spindel und
Präzisionslager GmbH

Gleitgelagerte Spindeln

MGF-Hydrodynamik-Feinbearbeitungsspindel DRF

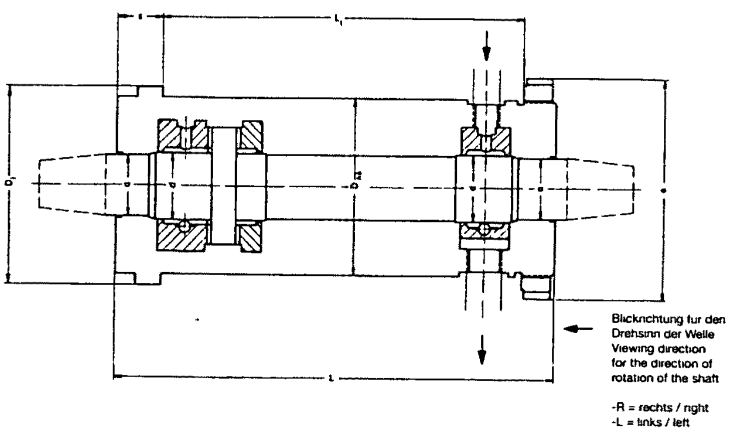
MGF hydrodynamic fine-boring spindle DRF



mit MGF-Lagern
in Flanschausführung
für hohe Arbeitsgenauigkeit
Rundlaufgenauigkeit ≦ 1µm

with MGF bearings
in flanged design
for high working accuracy
Concentricity ≦ 1 µm

Schmierart:
Fremdschmierung
Lubrication type:
external lubrication



Kurzzeichen/Reference	D_{h6}	D_1	L	L_1	a	d	e	s
DRF 60	60	70	150	117	18	20	75	20
DRF 80	80	90	200	165	28	30	98	20
DRF 90	90	100	250	208	32	35	110	24
DRF 100	100	110	250	207	35	40	125	24
DRF 110	110	125	300	249	45	50	140	30
DRF 120	120	135	350	298	50	55	150	30
DRF 140	140	155	400	345	60	65	175	30
DRF 150	150	165	400	343	65	70	190	30
DRF 160	160	180	450	437	70	75	200	35
DRF 180	180	200	500	436	85	90	220	35
DRF 200	200	220	550	484	95	100	240	35

Die Wellenenden werden nach gewünschten Anschlußmaßen gefertigt. Andere Größen auf Anfrage.
The shaft ends are manufactured to specifications. Other sizes on request.

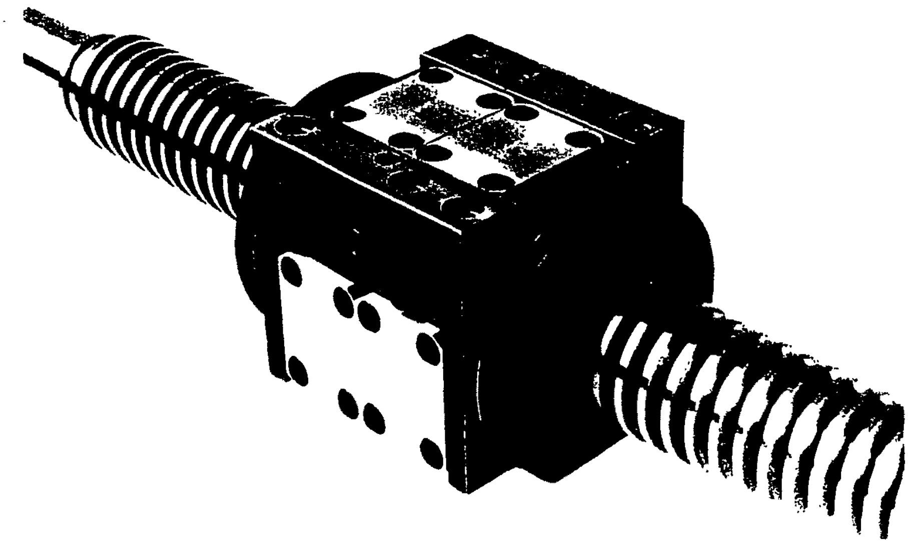
SPL Spindel und
Präzisionslager GmbH

附件二、液靜壓導螺桿設計技術資料
(Hyprostatik 技術資料)

HYPROSTATIK
Schönfeld GmbH

Technical Information

Hydrostatic Leadspindle



HYPROSTATIK Schönfeld GmbH, Zillenhardtstr. 19, D-73037 Göppingen
Tel.: xx49 (0)7161/818611, Fax.: xx49 (0)7161/812782,
E-Mail: hyprostatik@imos.de, Internet: http://www.hyprostatik.de

HYPROSTATIK Schönfeld GmbH
Fraunhoferstraße 8
D-73037 Göppingen

Index

HYPROSTATIK Schönfeld GmbH, Zillenhardtstr. 19, D-73037 Göppingen
Tel.: xx49 (0)7161/818611, Fax.: xx49 (0)7161/812782,
E-Mail: hyprostatik@imos.de, Internet: http://www.hyprostatik.de

1. Leadscrew with hydrostatic nut instead of ballscrew

Even high precision ballscrew systems need hardly different drive torque at small changes of position cause of the ball backlead and form and measure errors on ball ways.
Especially at the high loaded return areas of the balls, vibration are produced, which can be heard as the typical well known sound at high speed. To reverse the move of a ballscrew, the motor needs to reverse the minimum drive torque from one direction to the other at no move cause of the backlash of the ballscrew. This is bad for precise positioning. Inadequate damping and deficient life of ballscrew is especially known, when a small area is high loaded, when high loads moved slowly ore if high accelerations are needed.
To avoid described problems, herein described lead screws with hydrostatic nut have been developed. This nut shows extra ordinary damping, free of wear, very low and on 360° constant friction-moment and excellent quiet running. Even on high prestress there is no reversal step of the friction torque at reversing motion, which lead to best positioning precision. The nut can be supplied with clearly higher stiffness than a ballscrew nut.
The thread of the hydrostatic lead system is a modified trapezoid thread.
Selecting the useful standard diameter, the number of working turns of the nut, the pump pressure, oilviscosity and the size of the flow, the hydrostatic lead screw system can be adapted extensively to different demands of stiffness, rpm, loads on both directions.

2. Types of hydrostatic leadscrews

2.1 Radial loadability of a hydrostatic nut

Hydrostatic nuts can be supplied with or without radial loadability. Hydrostatic nuts, without radial loadability centre the lead spindle very low. This type is only for short leadscrews with radial bearings at the end, which centre the leadscrews in the nut, or for very short one side beared leadscrews. Using for a leadscrew a single bearing could be cheaper than a double bearing version.
Nuts with radial loadability have several circle ring segment hydrostatic pockets per thread turn, where every segment has it's own oilsupply. Leadscrews with hydrostatic nuts are especially for single beared leadscrews, for long or leadscrews with high rpm. Leadscrews with hydrostatic nuts for radial forces need higher expendure for production and mounting.

2.2 Double bearded hydrostatic lead system.

Normally leadscrews have a bearing for radial support at both ends and one axial a bearing at one end, so one radial bearing can move axial. Cause of the different distances between the axial bearing and the nut, the stiffness of the part leadspindle is different too. The stiffness is high when the distance is small - the stiffness is low, if the distance is large.

To increase the stiffness of long spindles or at high stiffness demand or if the stiffness should be independent of the position, leadscrews can be assembled with pull prestress. This pull prestress has to been taken by two axial bearings at the ends of the rotating leadscrews. Cause the size of the forces on the axial bearing cause by the pull stress is influenced strongly by the temperature of the leadscrew and machine parts around, so there is the danger of over load and destruction of the axial bearings.

An alternative solution to avoid the overload destruction of axial bearings is to use a hydrostatic system with fixed, prestressed leadscrew and a rotating hydrostatic nut.

2.3 Rotating leadscrew or rotating nut?

The main argument for use of a hydrostatic leadscrew system with a rotation nut or a rotating screw are:

- the system with rotating nut needs space for a motor in the slide with belt driven or direct connection. At rotating leadscrew, the motor can be connected at one end of the leadscrew.
- At long spindles, the centrifugal mass of the rotating nut is smaller than the centrifugal mass of the spindle with all rotating parts.
- At long or/and high speed rotating leadscrews, it's important, not to go over the critical rpm caused by bending swinging.
- A leadscrew with rotating nut can be easier controlled by the CNC cause there is less time distance between the turn and the linear motion caused there is no torsion spring effect of the leadscrew.

The rotating oil transmission to the hydrostatic nut and the bearing is included and is supplied complete. The drive of a hydrostatic nut can be done with a belt. We are developing now a hollow servo motor with a specialist, in order to be able to supply a rotating hydrostatic nut with bearings, rotary transmission lead through and direct motor.

2.4 Fixture of hydrostatic nut with rotating leadscrew

Hydrostatic nuts are fixed with screws through a flange to the slide or machine bed. You can select a round flange or a square flange. Please look at Drw. 6 for the nut standard size 50.
These two normal sized flanges of the hydrostatic nut should be used if enough space is available. If not enough space is available for the standard flange, the small flange type might fit, which need a special hole in the slide. (see Drw.7 for size 50)

These type of hydrostatic nuts has an integrated PM-flow controller system, so only one oil supply from the pump is needed. One type of those hydrostatic nuts can take radial forces, multiple less than axial forces, but enough to carry the weight of a short spindle assembled horizontal. For the small flange type of the hydrostatic nut, a attachment block is available to screw on the slide, in which the nut can be assembled - see Drw.8 for size 50.

2.5 Hydrostatic leadscrew for high speed

Standard hydrostatic leadscrews size 50 with 10mm pitch can be used op to a linear speed of 30 m/min max. at 3000 rpm. At short spindles higher speeds with low viscosity oil are possible.
When higher slide speeds are needed, leadscrews with larger pitch should be used. Those need for the same feed force a higher torque at the motor. At higher pitch, the changed transmission between motor and slide results less precision of positioning, machine way and stiffness at same CNC-Quality.

3. Advantages at use of our PM-flow controller

Cause of the extraordinary features of our patented PM-flow controller, 4 to 5 times higher stiffness can be reached than same systems with capillary tubes .Further with PM-flow controller, up to 90% of the pump pressure can be used in the hydrostatic pockets.This means that a difference pressure of 80% of the pump pressure, between the right and the left part of the nut can work against the axial load, without reserve.
Only by use of PM-flow controller instead of capillary tubes hydrostatic leadscrew systems with high stiffness and load ability could be produced economical .

4. Design information

4.1 Oilsupply, oil exit, back lead of the oil

The PM-flow controllers, which regulate the flow and the pressure of the hydrostatic pockets, are integrated in the hydrostatic nut. It needs to design only one oilsupply to the nut and no controllers between the hydraulic aggregate and the nut.
Normally hydrostatic leadscrews are installed in the guide way under a covering. There the oil can go out at both ends of the nut.
In some cases, the oil output at both nut ends can not be accepted. For this case, sealing has been developed , which are not free for the series now at end of 1997.
Using this sealing, a complete tightness can not be reached. Small leakage will be normal. Even now, we have no information on the life of the sealings.

4.2 Self locking

In opposite to ballscrews, hydrostatic leadscrews with standard pitch locks itself, short time after „turn of“ the hydrostatic. Cause of this, there are some essential advantages at vertical use especially at assembly and repair.

4.3 Installation space and position

Cause of the special system of hydrostatic nuts and the attached PM-flow controllers, the needed space for a hydrostatic nut is normally more than for a according ballscrews nut. Never the less, we made a nut with small sized flange size 50, which is all most adapted to the according ballscrew nut in order that the space for a ballscrew is enough for a hydrostatic leadscrew of same size. The hydrostatic leadscrew can be used at any position.

HYPROSTATIK Schönfeld GmbH, Zillenhardtstr. 19, D-73037 Göppingen
Tel.: xx49 (0)7161/818611, Fax.: xx49 (0)7161/812782,
E-Mail: hyprostatik@imos.de, Internet: http://www.hyprostatik.de

4.4 Crash - Information's

The hydrostatic leadscrews can be overloaded a very short time e.g. if the slide has a crash, without getting contact between nut and leadscrew. This may avoid a damage of the hydrostatic leadscrew in some crashes. But this will lead to a higher crash-stress in the drive system.
It is important not to loose the system by turning the nut or the leadscrew. This will damage the leadscrew.
There must be designed a stop bolt, which stops the slide at the end of the guide way, which can be loosened. After a crash, the hydrostatic leadscrew can be used again, when there is no more stress and force an the leadscrew any more and it is not damaged.

5. Technical data

5.1 Main measure and technical data

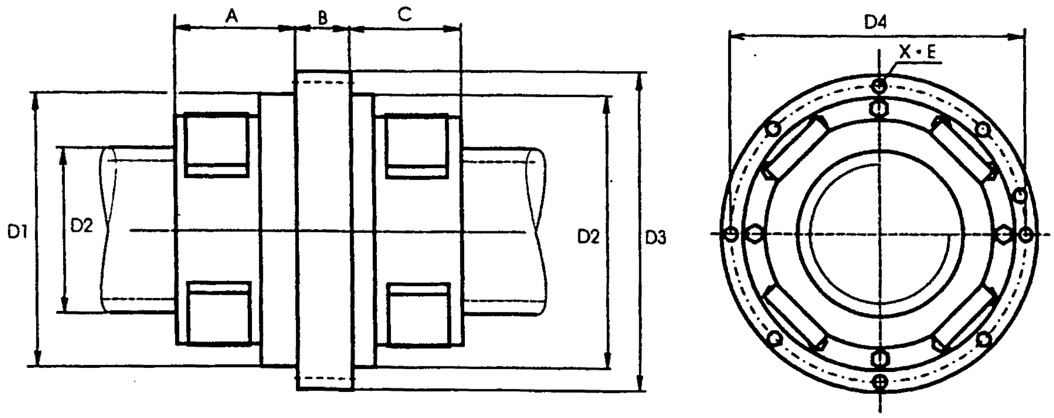
Table I list technical data of hydrostatic leadscrew systems of different sizes. All listed loadability are calculated with 50% reserve and max. pump pressure of 80 bar. In special case pump pressure of 160 bar with double loadability may be possible.

Size		50	63	80	100	125	160
Thread - O.D.	mm	52	65	80	100	125	160
Thread - I.D.	mm	36	45	55,5	69,5	88	112
Nut - I.D.	Mn	37	46	57	71	90	114
pitch:	mm	10	12	16	20	20	25
flank angle:	°	20	20	20	20	20	20
max - turns:		6	6	6	6	6	6
surface / turn:	cm^2	8,1	12,7	18,9	28,6	44,1	74,6
min. cut diameter:	cm^2	10,2	15,9	24,2	37,9	60,8	98,5
max. loadability at 80 bar/turn: *)	kN	3,7	5,7	8,5	12,8	20,0	33,3
max. loadability at 80 bar/6 torns: *)	kN	22,0	34,0	51,0	77	120	200

Table I Measure and technical data of hydrostatic leadscrews
*) witch 50% load reserve
1997: leadscrews size 50 available in short time, others on request

5.2 Measures of Flange nut

Table II list the main measures of the hydrostatic nut according to Drw. 1. Measures of size 63 to 160 bases on designs for special applications and should give an idea to the possible measures. According to the loadability, smaller sizes might be available.



Drw. 1: Drawing of hydrostatic nuts.

Size		50	63	80	100	125	160
„D1“	mm	52	65	80	100	125	160
„D2“	mm	110	130	160	185	220	250
„D3“	mm	50	170	200	240	280	320
„D4“	mm	130	150	180	212	250	285
„A“	mm	70	90	115	145	145	160
„B“	mm	25	30	55	70	70	80
„C“	mm	60	70	80	81	85	100
„E“	mm	8,5	11	13	17	17	22
„X“	Stück	8	8	8	8	12	16

Table II, measures of hydrostatic nuts according to Drw. 1 for size 63 to 160 without obligation.

5.3 Loadability and stiffness

In Table III the loadability and stiffness is listed at 80 bar pump pressure, 6 turns per nut and 50% reserve. At different configurations, the max. load can be calculated proportional to the pump pressure and the number of turns of the nut. The stiffness can be calculated proportional to the number of turns of the nut but only rough proportional to the pump pressure.

size	50	63	80	100	125	160
Max. Load	22	34	51	77	120	200
Axial stiffness	2,5	3,7	5,5	8,5	12,5	20

Table III, loadability and stiffness of hydrostatic leadscrews at 80 bar pump pressure and 50% load reserve and each 6 turns

5.4 Data for oilsupply, loss energy and speed for some examples. In table IV some examples with extended data are listed especially needed oil flow, oil type, oil heating, total loss energy at no and max. speed according to max. speed.

Spindel - size			50	50	50	80	160[2]
max. speed		rpm	2000	4000	4000	1000	160
lead / pitch		mm	10	10	25	25	25
max. speed		m/min	20	40	100	25	4
carrying thread turns							
right			5	4	4	5	6
left			3	4	4	2	4
loadability	right [1]	kN	10	10	10	50	500
	left [1]	kN	5	10	10	15	320
axial stiffness of the nut		N/µm	1250	1000	1000	1500	4000
pump pressure		bar	50	63	63	100	160
oiltype according			VG32	VG22	VG22	VG68	VG100
needed oil flow at							
oil temperature 40°C		l/min	1,3	2,8	2,8	4,7	5,8
friction power of the nut at							
max. rpm		W	90	180	180	160	68
max. total loss energy (pump + friction power)							
at 0 rpm		W	145	390	390	1050	2000
at max. rpm		W	235	570	570	1210	2070
oil heating							
at 0 rpm		°C	4,2	5,2	5,2	8,2	11,8
at max. rpm		°C	10,5	12,0	12,0	14,0	13,0

Table IV: technical data of produced and projected hydrostatic leadscrews.

[1] with 50% load reserve

[2] with 26% load reserve at max. 32 °C oil temperature

HYPROSTATIK Schönfeld GmbH, Zillenhardtstr. 19, D-73037 Göppingen
Tel.: xx49 (0)7161/818611, Fax.: xx49 (0)7161/812782,
E-Mail: hyprostatik@imos.de, Internet: http://www.hyprostatik.de

6. Use and assembly of hydrostatic leadscrew systems

6.1 Receiving a hydrostatic leadscrew

If oilsupply is turned off and the spindle is not installed e.g. at transportation, the spindle can be moved axial in the spindle. This clearance depends on the size and is between 25 to 50µm axial and 34 to 69µm radial caused by the flank angle of 20°.

To avoid damage of transport, the leadscrew is shipped disassembled aside the hydrostatic nut.

6.2 Assembly of a hydrostatic leadscrew system

Cause there are no loose parts, the leadscrew can be turned in easily. To avoid damage at the hydrostatic nut, it is necessary to put on the insert end of the leadscrew a plastic protecting bushing which outer diameter is a bit smaller than the inner diameter of the hydrostatic nut, see Drw. 2. The spindle is almost centred if the plastic protecting bushing is in the nut. Moreover this, we advice to lead the leadscrew at its outer thread diameter with a flange shown in Drw. 2.

Caution: screw in very carefully

Every leadscrew is paired to a hydrostatic nut. Only leadscrew and nuts, which belong together (look at the series number) can be used together. The sides of the leadscrew flanks are paired to the flanks of the nut. So one end of the leadscrew is only allowed to turn in one side of the hydrostatic nut.
Please lock at the definition drawing where you can see the correct assembly. (look at oil supply hole)
The right position of the nut is secure identified by the oil supply whole. Some times the nut can be identified by the not symmetrical form.
After the leadscrew is almost in the first half of the nut, the leadscrew should be turned in the rest with a bit pull.
At every hydrostatic leadscrew system, a identification drawing and a assembly information is send with.

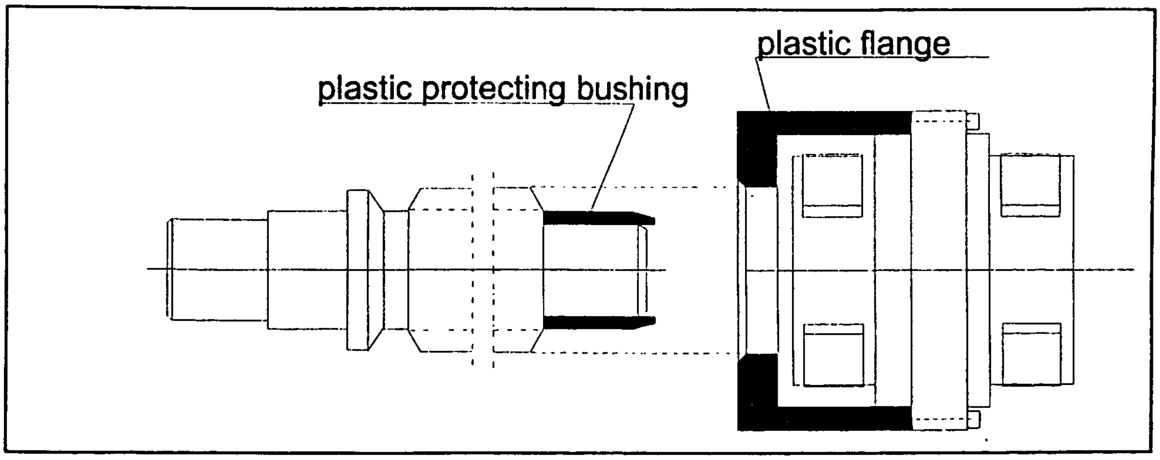


Abb. 2 assembly protecting bushing and flange

6.3 Adjustment of the hydrostatic nut to the leadscrew

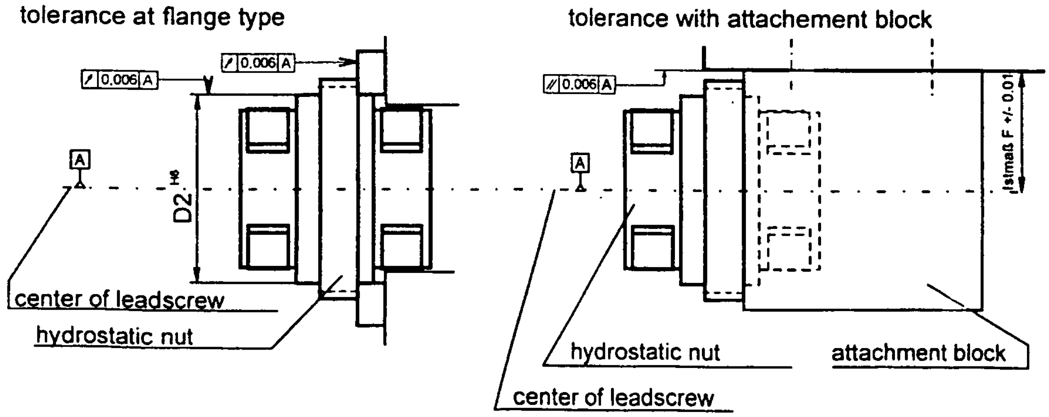
If the hydrostatic nut should be hold in correct position without hydraulic pressure e.g.

- to measure the attach surface at the base type, see Drw. 3,5
- to adjust a mounting ring see Drw. 3, 4
- or to hold the not fixed nut in correct position

a special support axle, which has ends like the leadscrew, is needed. For this, the nut is fixed to the support axle at diameter D2 and the plain surface like it shown in Drw. 4. or 5.
When the hydrostatic leadscrew system is used together with a hydrostatic guide way, the leadscrew should be adjusted centerly to the hydrostatic nut at working hydrostatic guide way.

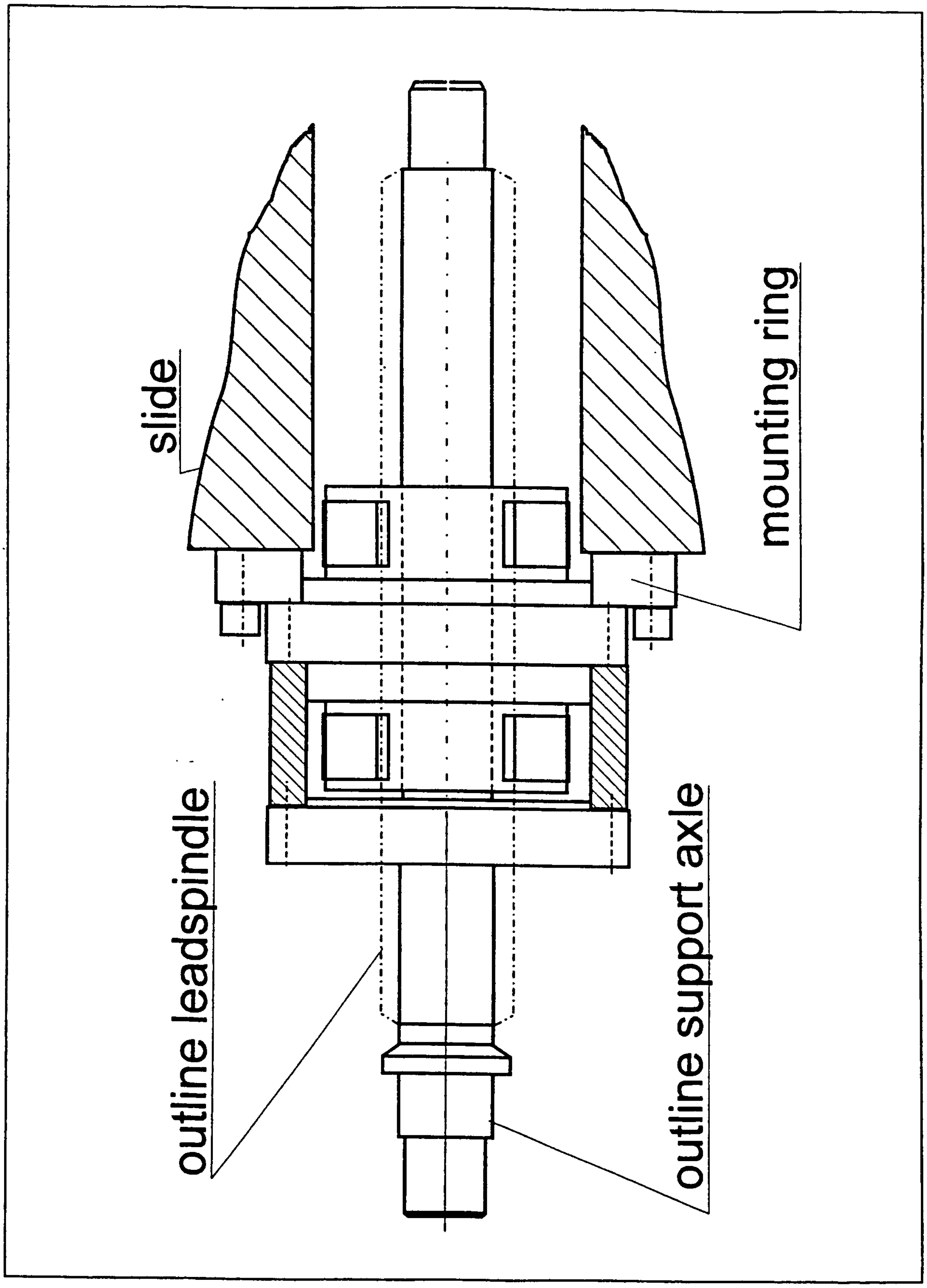
6.4 Assembly tolerances for hydrostatic leadscrews

The installation tolerances of the hydrostatic leadscrews system is comparable to high precision ballscrews. The obligate allowed tolerances are defined in the order drawing we make for every spindle type. Tolerances without obligation are in Drw. 8.



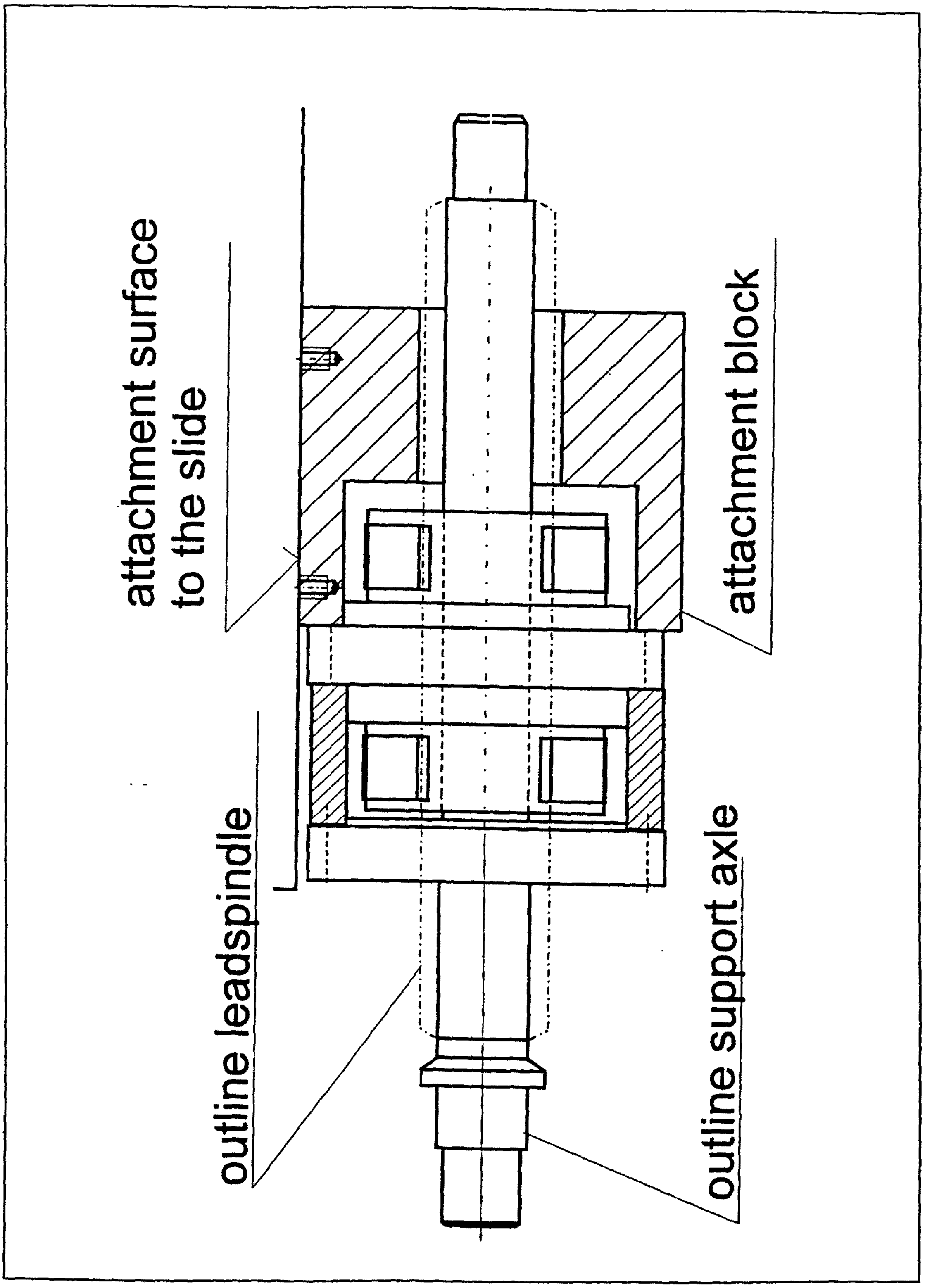
Drw. 3: Installation tolerances

HYPROSTATIK Schönfeld GmbH, Zillenhardtstr. 19, D-73037 Göppingen
Tel.: xx49 (0)7161/818611, Fax.: xx49 (0)7161/812782,
E-Mail: hyprostatik@imos.de, Internet: http://www.hyprostatik.de

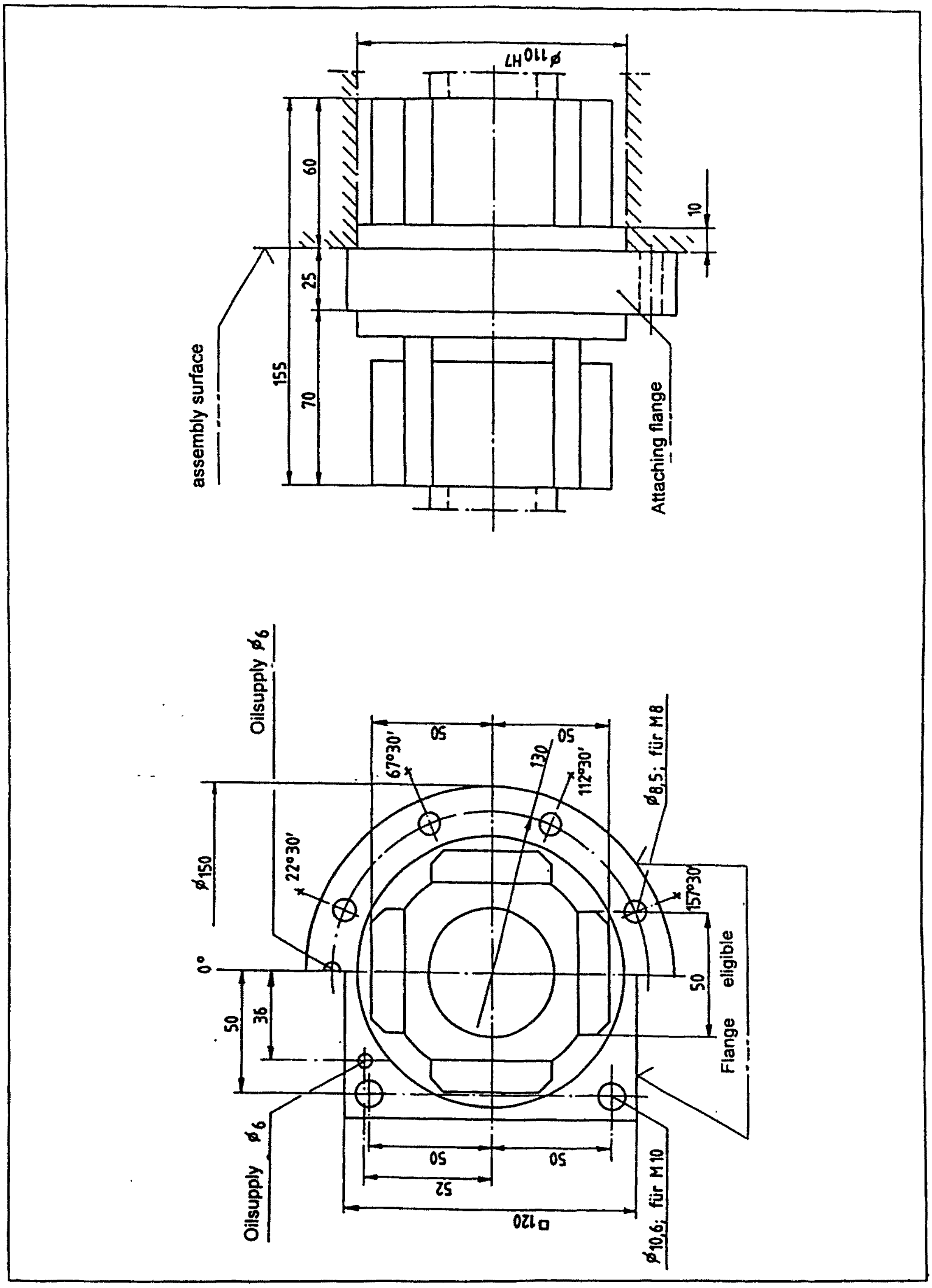


Drw. 4: Positioning hydrostatic nut - flange type

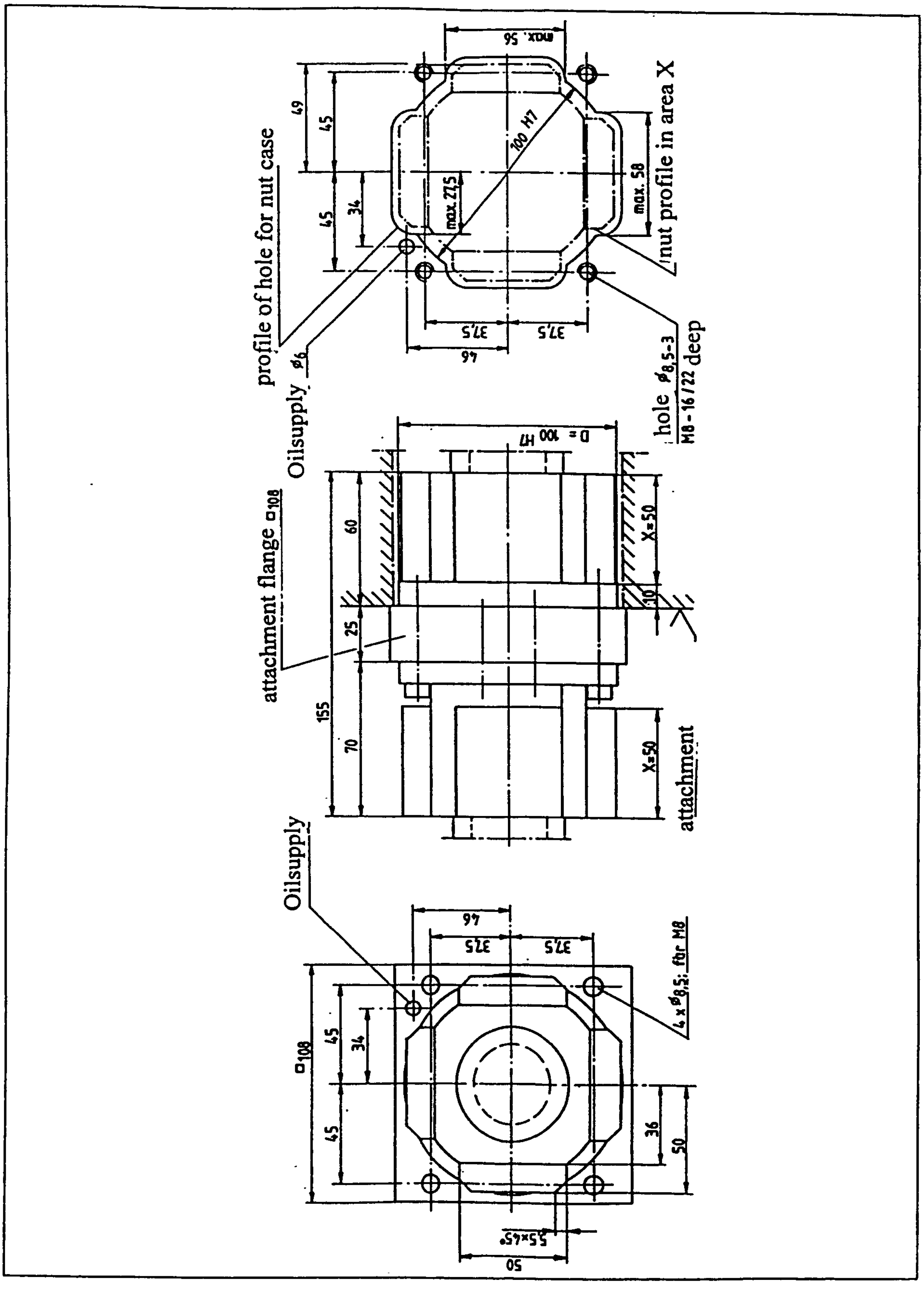
HYPROSTATIK Schönfeld GmbH, Zillenhardtstr. 19, D-73037 Göppingen
Tel.: xx49 (0)7161/818611, Fax.: xx49 (0)7161/812782,
E-Mail: hyprostatik@imos.de, Internet: http://www.hyprostatik.de



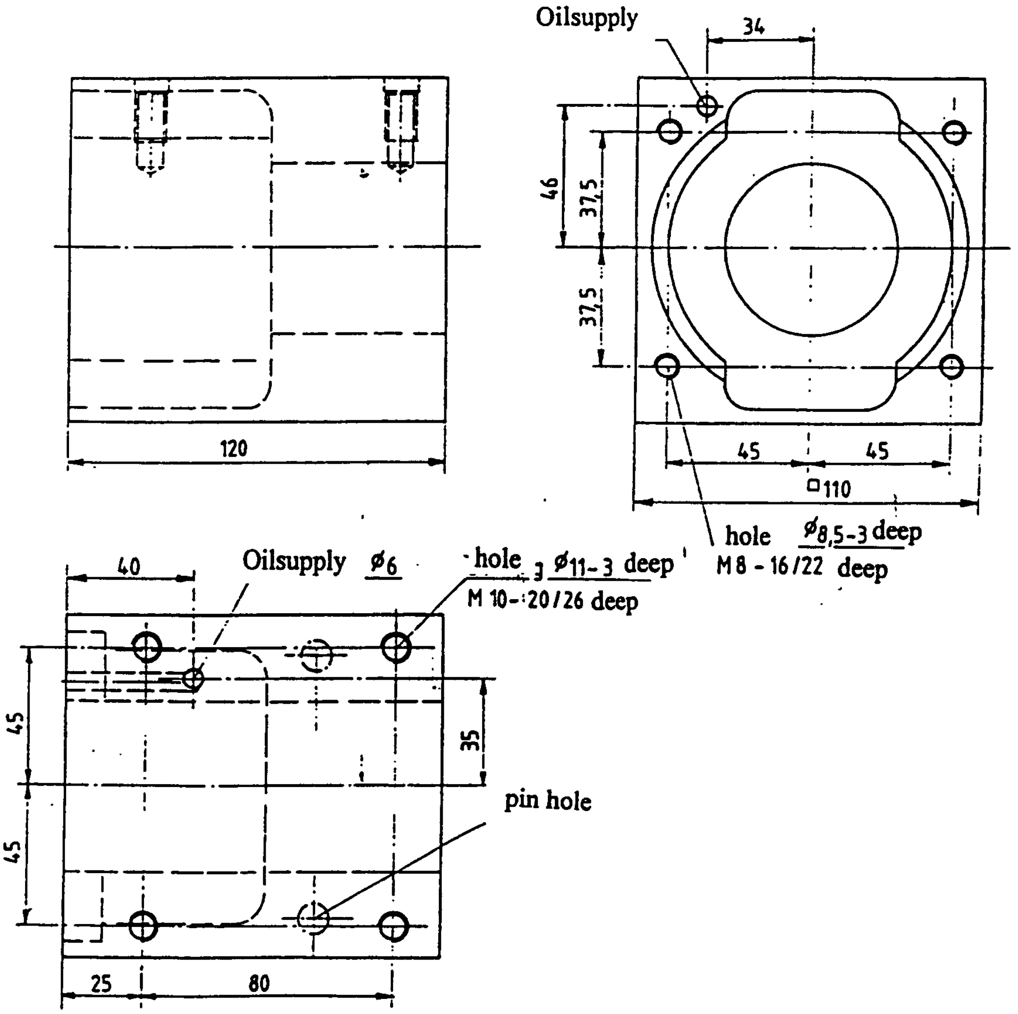
Drw. 5 : Positioning attachment block



Drw. 6: Hydrostatic leadscrew system, measures for size 50 normal flange



Drw. 7: Hydrostatic leadscrew system, measures for size 50 small flange

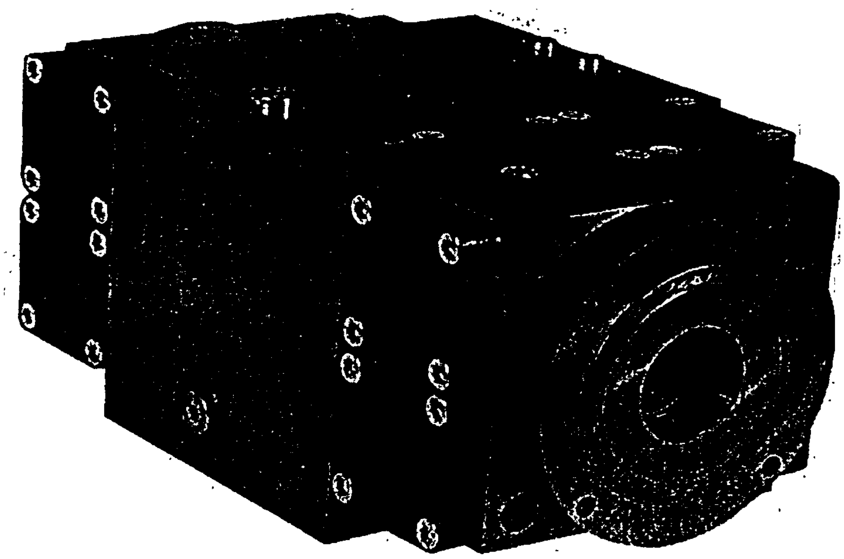


Drw. 8: Hydrostatic leadscrew system size 50, attachment block for small flange

附件三、液靜壓主軸設計技術資料
(Hyprostatik 技術資料)

Technical Information

Hydrostatic Spindles



HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel.: xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik.de, Internet: http://www.hyprostatik.de

Inhaltsverzeichnis

HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel.: xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik.de, Internet: http://www.hyprostatik.de

Technical information to hydrostatic spindles.

1. Advantage and disadvantage of hydrostatic spindles compared with different spindles systems.

advantages:
- **free of wear**;
- **multiple higher damping** than ball beard spindles;
- **excellent runout**;
- good friction heat removal with the
- there is the danger of
- easy **supervision** of bearing features and forces by measuring the pressure of the one or more pockets;

disadvantages:
- higher costs by additional needed hydraulic power unit
- only **with capillary** tube system or comparable systems, **not with PM-flow controller** spindles can carry only small forces to avoid damage by overload
- difficult calculation and optimisation

Advantages mit System "HYPROSTATIK®" with PM-flow controller:
- **very high stiffness possible;**
- **multiple lower loss energy;**
- **very high loadability;**
- **low heating in the bearings;**
- **potencies higher vibration damping optimised with computer calculation;**
- spindle **can run with max. load all time even at max. speed** without wear and stiffness loss;
- almost **rpm independent features.**

2. Advantages of hydrostatic spindles System "HYPROSTATIK®" with PM-flow controller.

At use of capillary tubes for control of the oil flow to the hydrostatic pockets, the oil flow to through the capillary tube is proportional to the difference pressure over the capillary tube. So the flow is reduced at increasing pressure in the pocket. In opposite to a system with constant flow, the gap will change hardly to get the needed pocket pressure change at changing pocket load.
At use of our PM-flow controller, more oil is feeded in the pocket at increasing pocket pressure. The same change of pocket pressure is reached with a much smaller change of the gap than using constant flow or capilary tube system. At proper dimensioning of our PM-flow controller, a almost endless sized stiffness can be reached.

By using of HYPROSTATIK PM-flow controller instead of capillary tubes multiple higher stiffness and multiple less displacement can be reached compared with usual capillary tubes. A stiffness increase of 4 to 5 times is realistic.

2.1 Multiple higher function safety compared with capillary system.

2.1.1 Minimum gap in the radial bearing at loaded spindel.

Cause of the curved form of the circle formed hydrostatic gap of radial bearings, only direct in force direction, the gap is reduced same size than spindle displacement. With larger angle to force direction, the gap reduction is smaller according cos-function. At load of a 4 pocket radial bearing in direction on the land between two pockets, the gap in same pockets in 90° angle to the force keep constant. In opposite to hydrostatic pockets at plain surfaces, this curved formed hydrostatic pockets need a essential larger displacement to reach a comparable flow off resistant.

Using capillary tubes for flow control to hydrostatic radial bearings
large displacement of the spindle follow even at medium load, caused by curved land form and in chapter 2 described oil flow reduction at increased load. Often a force which should be able to be carried caused of pocket surface and pump pressure can not be taken cause the spindle get contact before the flow off resistance is enlarged properly. This problem get more worse by the heating of the oil at rotation of the spindle.

Using PM-flow controller for flow control to hydrostatic radial bearings
the rising oil flow to the larger loaded pocket will lead to much smaller displacement. This also reduce the influence of curved form of the frame of a hydrostatic radial bearing pocket. With PM-flow controller from HYPROSTATIK® it is always possible to get a large pressure increase in the loaded pocket at sufficient minimal distance between spindle and bearing.

2.1.2 reduction of min. gap in the loaded bearing by oil heating of friction of the rotating spindle

The friction power is inverse proportional to the gap height and increase with the square of spindle speed.

At capillary tube flow supply to hydrostatic pockets
as above explained, the gap of a loaded pocket will get hardly smaller, which drastically increase the friction in these pocket. This hardly increased friction power heats the reduced flow of this pocket, which increase oil temperature and reduce the viscosity extreme in the land area of the pocket. The reduced oil viscosity lead also to enlarged displacement and smaller gap at same load.

With increased speed, reduced viscosity of oil in the loaded pocket, the spindle displacement get larger and larger. At sufficient load and speed the spindle displacement get so big, that the spindle get contact with the bearing, which damage or destroy the spindle.
This coherence, which has not been noticed a lot of times in the past by other companies, is the reason, why many hydrostatic spindle break through and get damaged.

When PM-flow controller feed hydrostatic pockets,
the more loaded pocket get a enlarger oil flow. At increase load, the displacement of the spindle and the friction power increase in much less size than using capillary tubes. So the low increased friction power is spread to also increased oil flow. At proper dimensioned PM-flow controller it can be reached, that the rise of oil flow in the loaded pocket is same or bigger than the rise of friction power in the same pocket. So even at high forces, the oil temperature in the loaded pocket get not higher than in the unloaded pocket and the oil viscosity is not reduced.
This result that using the PM-flow controller from HYPROSTATIK® there is no danger of damage or destruction like it is possible using capillary tubes.

2.2 Essential higher loadability by use of PM-flow controller.

The PM-flow controller need a min. difference pressure of max 10% of the pump pressure. With that the max possible pocket pressure can be 90% of the pump pressure without reserve. Case the oil flow through the loaded pocket is very big – e.g. double size than unloaded – the gap size is sufficient in spite of the high pocket pressure. At usual adaptation with our PM-flow controller is the pocket pressure of the unloaded pocket less than 10% of the pump pressure. The difference pressure between two opposite pockets can reach 80% of the pump pressure to take high forces. So the loadability of pockets with PM-flow controller from HYPROSTATIK® is very high.

When a spindle with capillary tubes get loaded to 90% pocket pressure, the oil flow get to less than 20% (!) of the flow at unloaded spindle, at usual dimension of the oil flow. This flow is not enough to avoid contact between the spindle and bearing. So capillary tube based spindle can have only a max. pocket pressure of 70% of the pump pressure.
At usual calculation, the pocket pressure on the opposite unloaded pocket is reduced only to 30% of the pump pressure. So with capillary tubes the max. difference pressure between two opposite, one loaded, one unloaded pockets is only about 40% of the pump pressure to take force.

The loadability of a radial bearing by using the PM-flow controller of HYPROSTATIK® instead of capillary tubes is increase about 100%.

2.3 Hydrostatic spindle according system HYPROSTATIK® can take max. load at top speed without any wear.

As explained in chapter 2.1.2, the spindle according system **HYPROSTATIK®** can be loaded all time with max. calculated force even if the spindle is running at max. calculated speed all the time.
When capillary tubes feeded hydrostatic bearings, the max allowed force need to be clearly reduced at high rpm. This also same at ball beared spindles.

HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel : xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik.de, Internet· http://www.hyprostatik.de

2.4 multiple reduced loss energy and/or much higher speed possible

A important safety feature of a hydrostatic bearing is the min. hydrostatic gap at max force on the bearing. Comparable bearings have same min. gap at max. load.
Cause the flow in max. loaded pockets at feed with capillary tubes is hardly reduced, and at feed with PM-flow controller hardly increased, usually a much thinner oil can be used with PM-flow controller than with capillary tubes.
By using PM-flow controller from HYPROSTATIK® a multiple reduction of friction power or a much higher spindle speed can be reached than using capillary tubes or the spindles with preresistor opposite of the pocket.
A reduction of friction power by to 1/3 and a 50% higher max. speed of the spindle by using of PM-flow controller from HYPROSTATIK® are realistic.

2.5 heating of the spindle by friction power at high speed, cooling of the oil

By the reduced friction (see chapter 2.4) at comparable spindles a essential reduced oil heating is reached as using capillary tube feeded spindles.
At comparable loadability, a much lower pump pressure is needed when PM-flow controller are used instead of capillary tubes (see chapter 2.2), so the oil heating by the pump energy is also much lower with PM-flow controller than with capillary tubes.
A special low oil heating is reached, when the spindle with calculated with a bit enlarged oil flow. Especially at extreme high rpm a bit higher loss energy should be expected than min. necessary to get a spindle without heating usually known from ball bearing spindles.

A further possibility to reduce temperature changes of bearing parts is, to cover the spindle and bearing parts by a layer of heat isolation. When e.g. the spindle is covered by ceramic or the areas in the bearing which get contact with exit oil is covered with a layer of plastic, the heating of the bearing parts can be reduced hardly. Then the friction heating of the spindle is transported almost completely out of the spindle with the hydrostatic oil.

For low heating of a spindle it is necessary that the oil is cooled low under room temperature before it enters the spindle.

In enclosed technical desciption about different spindles, there is always the temperature increase, which the oil is heated by pump- and friction engergy when it pass the spindle. The typical heating at max. speed in this calculation is between 6 and 12°C. The oil heating at smaller speed is much lower.
By above mentioned means, the difference temperature of the bearing to room temperature can be limited to 6 to 1 °C. This make it possible to make a extreme cool spindle with a very low thermal move and a extreme low heat input in the machine.

3. Physical limits at calculation of hydrostatic spindles

3.1 Optimisation to min. loss energy.

As it is right in technical literature, min. loss energy is reached, if gap and oil viscosity is 0. Then the pump energy and the friction energy and the total loss energy is 0.

But it is not possible to use this in real. Min. total loss energy is reach, if viscosity is low as possible and the gap is as small as possible.
When the gap is fixed the min. total loss energy is calculated by pump- and friction energy with chosen oil viscosity, which lead to same size of pump- and friction energy.
If the oil viscosity is fixed, the min. total loss energy is calculated with a gap which result that the friction energy is three time higher than the pump energy.

At extreme high rpm, spindle calculation according above rules is normally not possible, cause than the heating of oil get too large and thermal disadvantages can not be avoided. In this cases, a enlarged oil flow a same friction energy will limit oil temperature to a lower level, the oil will be leaded out of the spindle on shortest way and the oil covered parts are heat isolated.

3.2 Optimisation for min. loss energy and best damping.

Low friction at fixed gap size request a low product by oil viscosity and land width (η x b). High damping at medium and high frequencies request a high product by oil viscosity and third potency of land gap (η x b^3). Both aims can be only fulfilled, if at given product (η x b) the oil viscosity η is chosen as low as possible and the land width b is chosen as big as possible. Lowest possible friction and best damping can only be reached by sufficient low viscosity and big land width.

The radial deflection at the spindle at cutting position result by the part of spindle bending and second by the deflection of the radial bearings.
With fixed spindle design and the stiffness of the radial bearings, a optimum distance between the bearings can be calculated, where the stiffness at working position is maximum.
Cause the spindle deflection result by the almost undamped bending of the spindle material, and the hydrostatic bearing have a excellent damping, it should be tried conception of the spindle, to make the spindle as large as possible, and the stiffness of the bearings only as large as necessary. Sometimes this lead to a lower total stiffness at the working position, but will enlarge total damping drastically.

4. bearing types

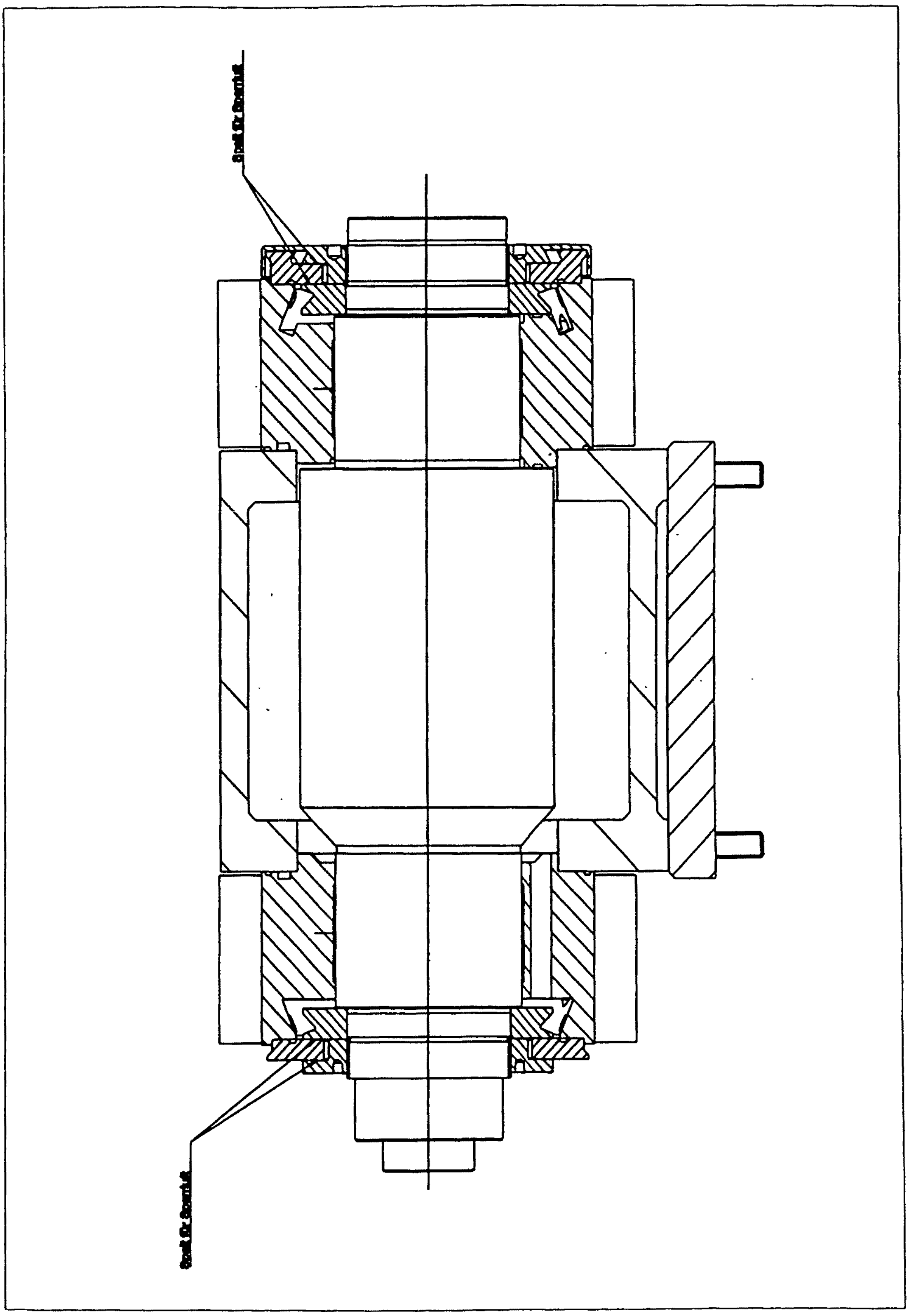
Our spindle bearings are produced mainly adapted to the requests of the application. For comparable applications there will be variety of same designs which can be adapted. Our design concept is presented in sketch 1:
At central spindle case, both side hydrostatic bearings with radial bearing pockets are attached. Around the bearing are the PM-flow controller, which control the flow in the pocket. The oil from the pump is spread by a channel at the axial flange side of the bearing. The oil enter the spindle case and split it up in the two bearings. The axial bearing pockets are at on bearing, which have two more PM-flow controller.

4.1 sealing.

To seal the bearing to entering dirt or liquid and to leaking hydrostatic oil, labyrinth sealings supported with pressure air are used especially at high rpm. At this sealing, the centrifugal force in the axial sealing gap support the sealing function of the sealing air at spindle rotation. Also this sealing type is free of wear. It is very important, that the oil can exit the spindle in sufficient sized pipe only down to the tank. It is alternative possible to use common contact sealing especially at lower rpm.

4.2 aeration of spindle bearings.

To reach the low loss energy level of the spindle, it is necessary to avoid that the spindle is running with all areas full with oil. To be sure that there is a low quantity of oil between the bearings the spindle need a small flow of air with a bit overpressure is needed. This can be done by the air pressure support of the labyrinth sealings. Surplus exit the spindle case with the hydraulic oil in the tank of the hydraulic power unit and need to be separated there. Above described design concept is used in workpiece spindles for grinders, which HYPROSTATIK have presented at the exhibition METAV 2000 in Düsseldorf. The spindle is sealed by a pressured air supported labyrinth sealing. The same concept, changed according the requirements, is used for spindles for high loads, used in lathes or milling machines. Technical data for such spindles are at page 11 of this information.



5. requirements on the hydraulic power system for feed of hydrostatic bearings

The hydraulic power unit for feed of hydrostatic spindles has the task to take the oil, returned from the spindle. It should separate the air in the oil, filter and cool the oil. With the pump the oil gets the for the spindle needed pressure and is transported to the spindle. The pump need to have low vibration. Al components need to be useful for the sometimes very low viscosity of the hydrostatic oil. The pump need to keep the pump pressure during the move of the spindle.

5.1 aeration of the oil.

The inner area of the hydrostatic spindle between the bearings need to be filled almost complete with air, except the oil exit from the bearing to the tank. This request, that the inner area need to have at least low enlarged overpressure against the atmosphere, by a constant small flow of pressured air. Normally this air is supplied by the sealing air automatically.
This air flow exit the spindle case with the hydrostatic oil and enter the tank where it need to be separated out of the oil before the oil can be sucked from the pump again.

5.2 filtering of the oil.

Our hydraulic power units in standard version have a circulation pump for oil supply to a heat exchanging unit. Normally this pump is combined with the pressure pump, which need only on motor for both pumps. To get a long live for the main pump, the main filter is positioned after the circulation pump, in order that the pressure pump can suck only filterd oil. For best secure the PM-flow controller to dirt, there is second filter after the pressure pump, which keep loosening of the pump and pipes of hydraulic power unit. This filter is positioned best very close to the spindle. If this is not possible, this filter can be assembled at the hydraulic power unit, but then the spindle is not secure to loosening of the pipes inner area between hydraulic power unit and spindle.
The filer after the circulation pump has filer quality 10 or 6μm. The filter after the main pump should have 10μm qualtity.

5.3 cooling of the oil.

The oil is cooled by a oil-fluid heat exchanger by a external cool fluid, or by a separate cooling unit. Cooling with a low cost oil-air heat exchanger is only possible at spindles with low max. rpm with low friction heating.
To keep the temperature of hydrostatic oil constant, the temperature of the external cooling fluid should stay as constant as possible. When a cooling unit is used, it should work continuos, which mean that the cooling power is controlled to the demand. Two point cooling units which only turn on and off are less useful.

5.4 oil supply at current malfunction.

Especially at high speed hydrostatic spindles, low viscosity oil and small land width is needed to reach best features. Emergency run features by sufficient hydrodynamic loadability can be reached only in exceptional cases. It is necessary to have always the full pump pressure at the spindle when it moves. Otherwise the spindle can be damaged immediately.

This is also valid at current malfunction

This can be reached with tree alternatives

5.4.1 By pressure storage between the pump and the spindle

This is the cheapest version at low flow volume out of the pressure storage, which need a very short time for breaking the spindle to 0 rpm. The disadvantage is that the hydraulic pressure is reduced with the flow out of the storage. To keep the pressure reduction in limits, the storage volume can be used only to 15, max. 20% of max. filling. If a spindle with oil flow of 10 l/min need to be feeded 6 seconds by a storage, a storage of 6 liter is necessary. This storage can be maintained only by specialists. The function of the storage is endangered by gas leakage. If malfunction by gas leakage should be excluded, the gas pressure need to be controlled.

5.4.2 With a self adjustable pump and flywheel on the pump shaft.

This solution can be used for longer breaking times of the spindle. For oil feed of the spindle a pump with self adjustable flow rate is used, which has a double max. flow rate than the spindle need max. at usual work. The controller of the pump adjust the flow of the pump that the requested pressure is at the spindle. Sparate beared and connected with the shaft of the pump, a sufficient dimensioned flywheel is fixed. At current malfunction the flywheel drive the pump for a certain time and the control pump compensate the reducing pump rpm up to the half . During this time, the pressure and the flow quantity for feed of the spindle is almost not reduced.

This alternative can be used for a breaking time up to 20 seconds.

This solution is endangered when the pump get stuck suddenly and by malfunction of the flow controller of the pump. Cause the malfunction of the pump will announced by a hardly increase of the motor current, the danger can be reduced by the usual supervision of the motor current.

5.4.3 With electrical storage (battery).

When a low voltage direct current motor is used for drive of the pump, this motor can be feeded a certain time after current malfunction by a electrical battery. A 12 Volt battery with 20 Ah capacity can supply 240 Watt for 3 minutes or almost 4,8 kW for 3 minutes. Alternative, the direct current motor can be changed to a AC-motor. With this expensive method the oil supply can be hold some minutes, depending on the size of the battery.

5.5 pressure pumps.

Eighter with constant flow or with self adjusting flow rate, pumps are available also for low viscosity oil.

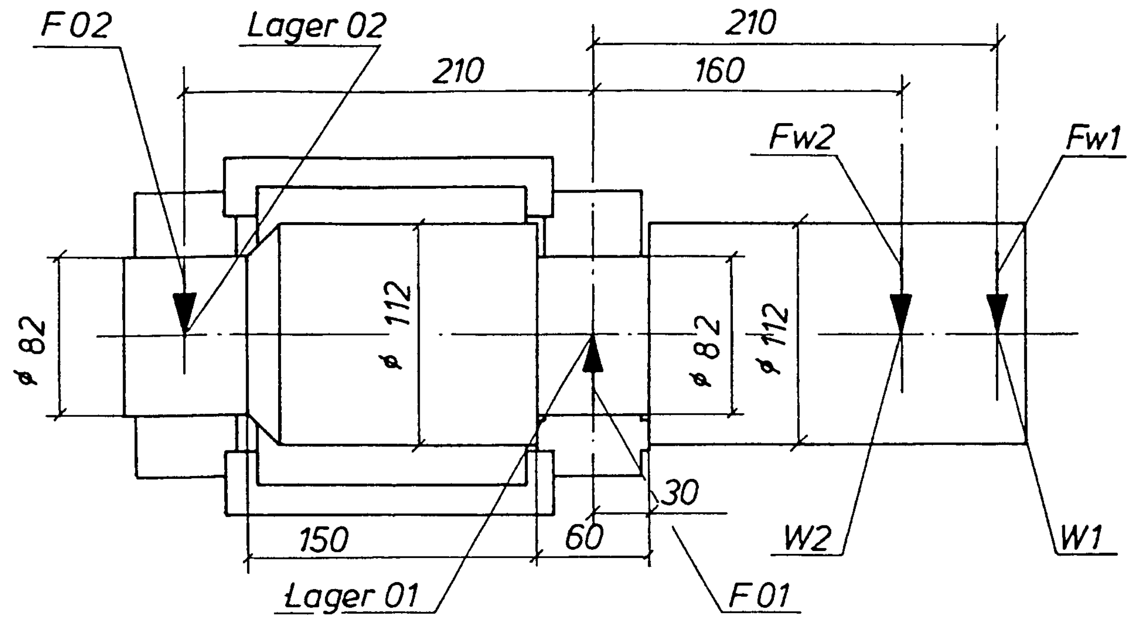
6. hydraulic power units.

On page 12 or 13 a drawing and a hydraulic plan of a hydraulic power unit with pump with constant flow rate and hydraulic storage and cooling unit is showed.
On page 14 and 15 same drawing and hydraulic plan show a hydraulic power unit with self flow adjusting pump, flywheel and heat exchanger.

Both hydraulic power units have show the usefulness already in practical us in many times.

HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel.: xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik de, Internet. http://www.hyprostatik.de

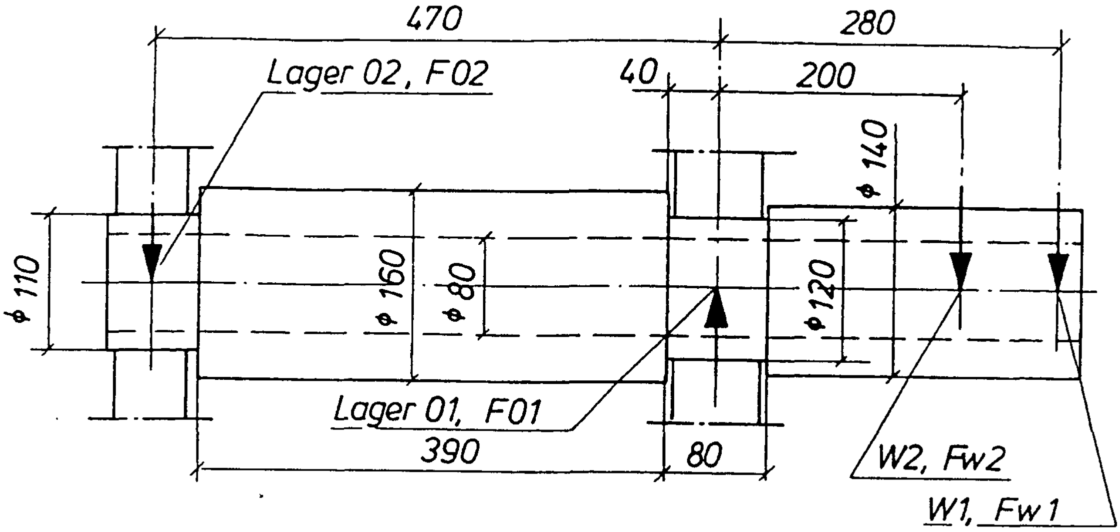
Workpiece- or grindingspindle for a cylindrical grinder



technical data of the spindle:

		radial bearing front	rear	double-axialbearing	all bearings
bearing number		L01	L02	L03/04	
bearing diameter	mm	82	82	86/110	
max. speed	rpm				3000
max. radial load Fw1	N				1500
max. radial load Fw2	N				1700
max load	N	3000	1500	1250/-500	
load reserve	%	100	300	100/150	
stiffness at point "W1"	N/µm				63
stiffness at point "W2"	N/µm				110
stiffness at bearing	N/µm	1080	900	300	
spindle angle deflection in the radial bearings	mrad	0,052	0,011		
oil type					VG 2
pump pressure	bar				50
max. oil flow at 35 °C	l/min	2,5	2,4	2,2	7,1
friction power at 2000 U/min	W	70	70	30	170
3000 U/min	W	150	140	55	345
oil heating at 3000 U/min	°C	7,5	7,5	5,5	6,3
pump loss energy with efficiency η = 0,8	W				920
max. cooling power	W				1270

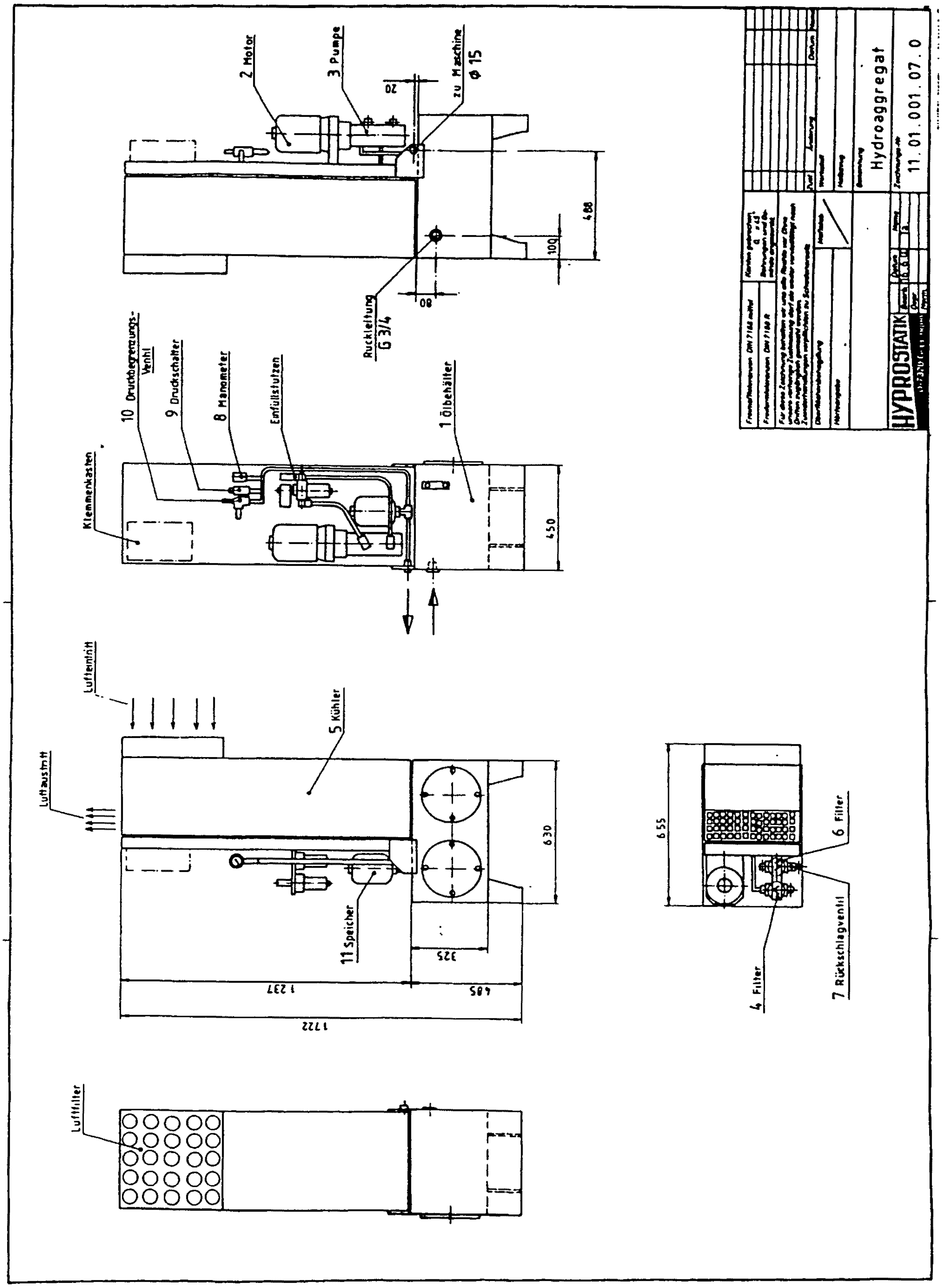
example: workpiece spindle for CNC-lathe, drive power 25 kW.



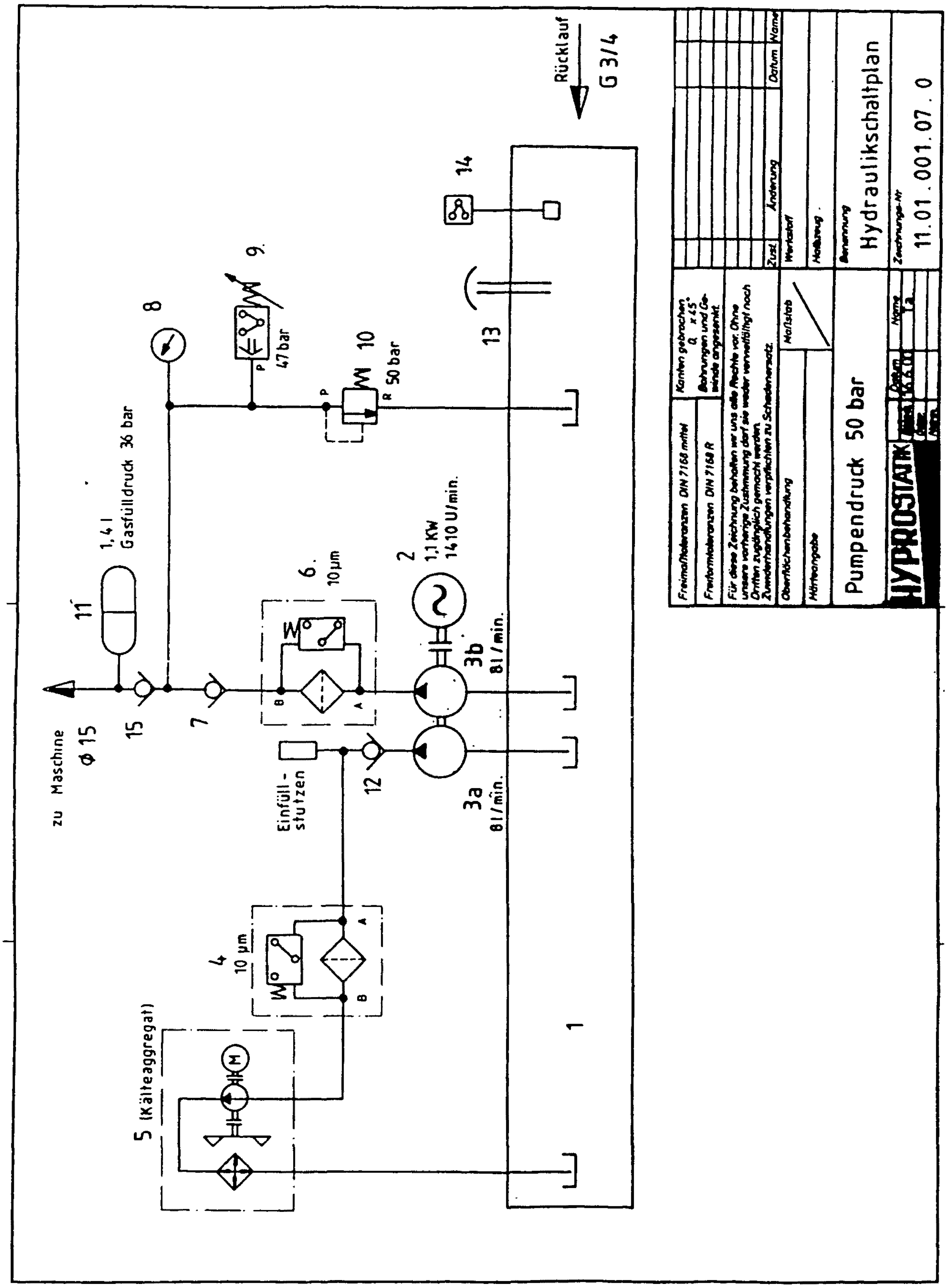
technical data of the bearing:

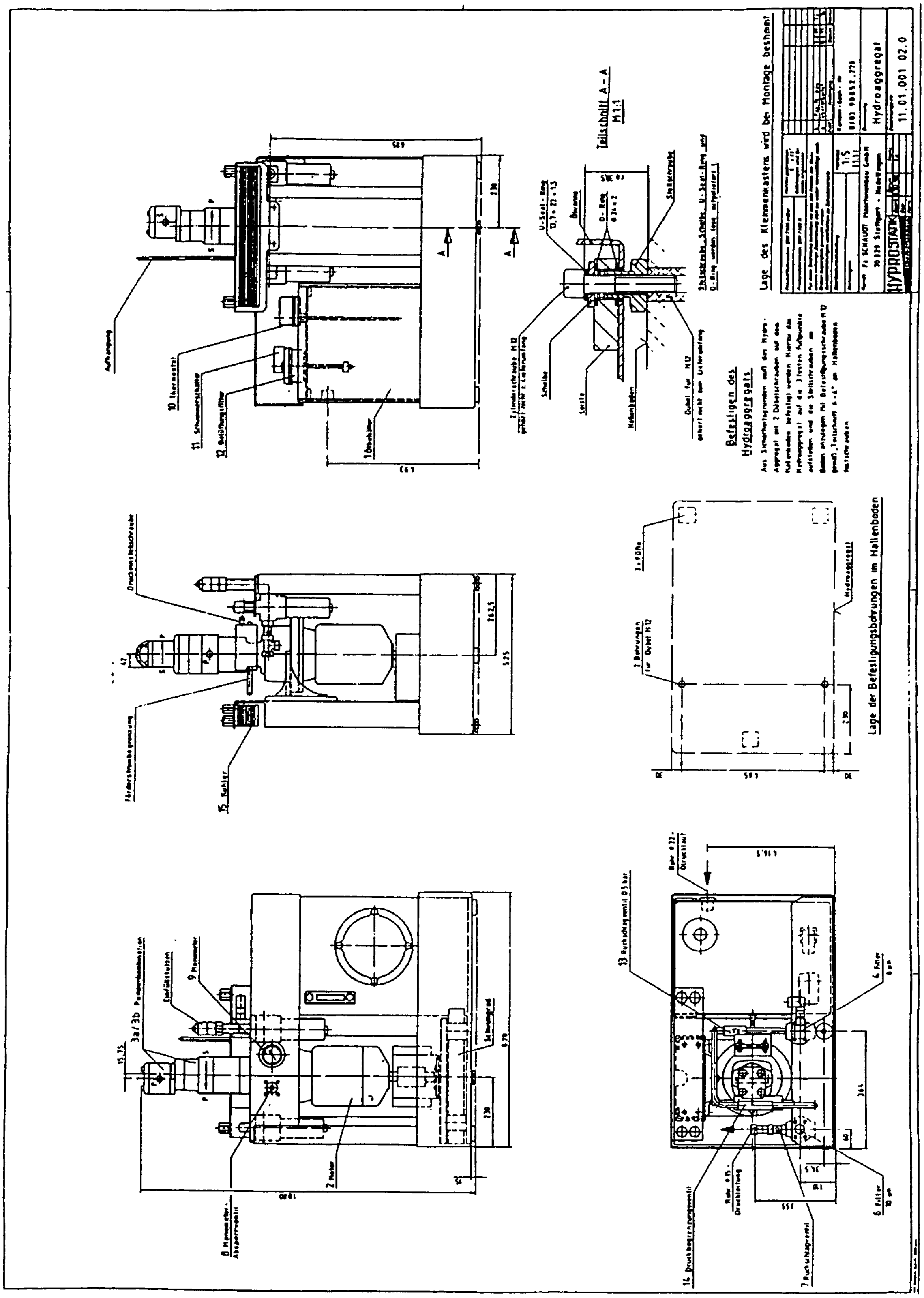
		radial bearing front	rear	double-axialbearing	all bearings
bearing number		L01	L02	L03/04	
bearing diameter	mm	82	82	86/110	
max. speed	rpm				4000
max. radial load Fw1	N				12500
max. radial load Fw2	N				14000
max. load	N	20000	16000	± 20000	
laod reserve	%	60	100	60	
stiffness at point "W1"	N/µm				115
stiffness at point "W2"	N/µm				220
bearing stiffness	N/µm	1400	1000	1600	
spindle angel deflection in radial bearing	mrad	0,2	0,006		
oil type about					VG 2
pump pressure	bar				80
max. oil flow at 35 °C	l/min	4,6	3,9	4,3	12,8
friction power at 3200 rpm	W	440	310	420	1170
4000 rpm	W	680	480	650	1810
oil heating at 3200 rpm	°C	11,5	10,5	12,5	11,5
pump loss energy with efficiency $\eta = 0,85$	W				2000
max. cooling power	W				3800

HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel.: xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik.de, Internet: http://www.hyprostatik.de

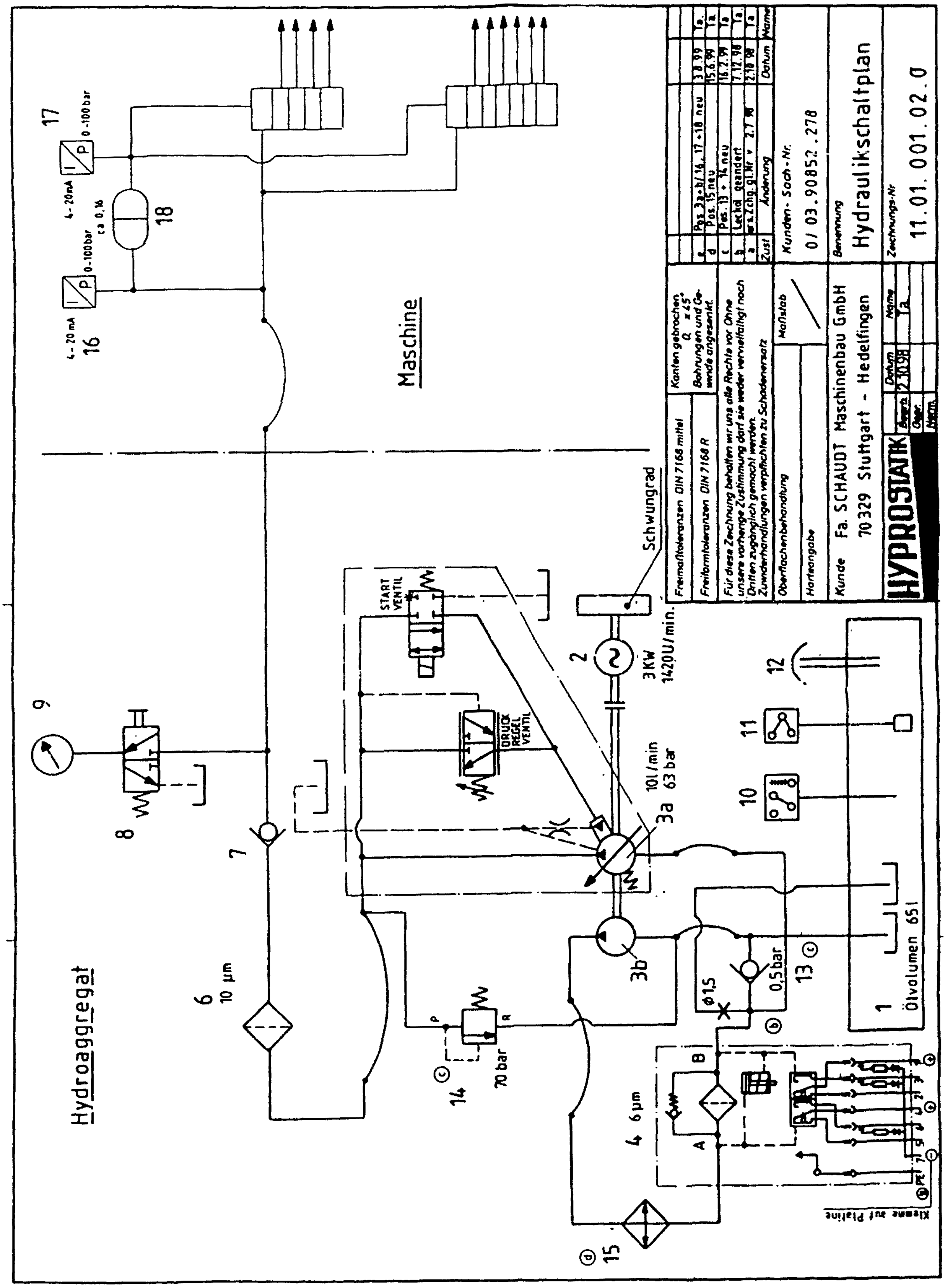


HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel.: xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik.de, Internet: http://www.hyprostatik.de


Rücklauf
G 3/4
zu Maschine
ϕ 15
15
7
11
1,4 l
Gasfülldruck 36 bar
8
9
47 bar
10
50 bar
6
10 µm
2
1,1 KW
1410 U/min.
3b
8 l/min.
3a
8 l/min.
12
Einfüll-stutzen
4
10 µm
5 (Kälteaggregat)
13
14
1
Pumpendruck 50 bar
Hydraulikschaltplan
11.01.001.07.0
HYPROSTATIK



HYPROSTATIK Schönfeld GmbH, Fraunhoferstr. 8, D-73037 Göppingen,
Tel.: xx49 (0)7161/965959-0, Fax.: xx49 (0)7161/965959-20,
E-Mail: info@hyprostatik.de, Internet: http://www.hyprostatik.de



Hydroaggregat
Maschine
Schwungrad
START VENTIL
DRUCK REGEL VENTIL
3KW
1420U/min.
10l/min
63 bar
70 bar
0,5bar
Ölvolumen 65l
4-20mA
0-100bar
Kunde
Fa. SCHAUDT Maschinenbau GmbH
70329 Stuttgart - Hedelfingen
Kunden-Sach-Nr.
0/03.90852.278
Hydraulikschaltplan
11.01.001.02.0
HYPROSTATIK

附件四、鈦合金加工刀具與參數選用
(SANDVIK 測試報告)

Titanium machining

SANDVIK Coromant

Characteristics of Titanium

- High strength to weight ratio
- Corrosion resistance
- Low thermal conductivity
- Reactivity at high temperatures
- Low elastic modulus

SANDVIK Coromant

Wear mechanics

- Chemical
- Abrasive
- <u>Thermal</u>

SANDVIK Coromant

Guidelines for Titanium machining

- Low cutting speed
- Adapt feed/tooth to radial depth of cut
- Cutting fluid
- "Sharp" tools
- Never stop feeding while tool in contact
- Rigid setups

SANDVIK Coromant

Face milling

Tool choice	Cutting speed, vc [m/min]	Feed per teeth, fz [mm/teeth]
CM245 -ML 1025	40-50	0.10
CM200 -PL 1025	40-50	0.15
T-MAX -32 2030	40	0.25

SANDVIK Coromant

Slotting

Tool choice	Cutting speed, vc [m/min]	Feed per teeth, fz [mm/teeth]
CM390Em -PL 1025	60	0.10
CM390LE -PL 1025	60	0.10
CM331 -WL 1025	50	0.10

Contouring

Tool choice	Cutting speed, vc [m/min]	Feed per teeth, fz [mm/teeth]
CM390Em -PL 1025	60	0.10
CM390LE -PL 1025	60	0.10

SANDVIK Coromant

Pocketing

Tool choice	Cutting speed, vc [m/min]	Feed per teeth, fz [mm/teeth]
CM390Em -PL 1025	60	0.10
CM390LE -PL 1025	60	0.10
CM200 -PL 1025	40-50	0.15

SANDVIK Coromant

Slotting CM390LE

Sandvik CM390LE dia40, z3, R390-11T308M-PL 1025

a_p [mm]	a_e [mm]	v_c [m/min]	f_z [mm/teeth]	MRR [cm^3/min]	Comments
40	40	60	0.1	229	Full slotting

Sandvik CM390LE dia40, z2, R390-11T308M-PL 1025

a_p [mm]	a_e [mm]	v_c [m/min]	f_z [mm/teeth]	MRR [cm^3/min]	Comments
60	30	60	0.12	207	Side milling

Sandvik CM390LE dia40, z2, R390-11T308M-PL 1025

a_p [mm]	a_e [mm]	v_c [m/min]	f_z [mm/teeth]	MRR [cm^3/min]	Comments
60	40	60	0.1	240	Full slotting

SANDVIK Coromant

Drilling

Tool choice	Cutting speed [m/min]	Feed per rev [mm/rev]
U-drill C = -53 H13A P = -58 H13A	100	0.08
Delta-C 1020 30-40 bar max 0.02mm t.i.r	40	0.12

SANDVIK Coromant

Tools for Ti6Al4V demo workpiece - aircraft

1. Facemilling surface of workpiece
   - Cutter: R245-125Q40-12M
   - Insert: R245-12T3E-ML 1025

2. Roughing outside profile of plane
   - Cutter: Engineered R390LE D=40
   - Insert: R390-11T308M-PL 1025

3. Roughing/semi-finishing/finishing nose pocket
   - Solid endmill: R216.44-06030-AK13L 1020

4. Roughing thin walls behind wings
   - Cutter: R390-016A16-11L
   - Insert: R390-11T316M-PM 1025

5. Roughing right engine pocket
   - Cutter: R216-12A20-045
   - Insert: R216-1202M-M 1025

6. Roughing upper right pocket
   - Cutter: Engineered 390LE D=40
   - Insert: R390-11T316M-PM 1025 (End insert)
   - R390-11T308M-PL 1025

7. Roughing wing pockets
   - Cutter: R390-020A20-11M
   - Insert: R390-11T308M-PL 1025

8. Roughing engine profile
   - Solid endmill: R216.33-10045-AC19P 1020

9. Finishing outside profile of plane
   - Solid endmill: R216.34-10045-AC22N 1020

10. Roughing fuselage pocket
    - Cutter: R200-028A32-12M
    - RCHT 1204M0-PL 1025

11. Roughing tail section pocket
    - Cutter: R300-015A20L-07L
    - Insert: R300-0724E-PM 1025

12. Finishing parts of fuselage and tail section pockets
    - Solid endmill: R216.44-12030-AK26L 1020

13. Finishing thin walls profile
    - Solid endmill: R216.34-08045-AC19N 1020

14. Finishing left wing pocket
    - Solid endmill: R216.33-20045-AC32P 1020

15. Roughing left engine pocket
    - Solid endmill: R216.44-12030-AK26L 1020

16. Semi-finishing upper left pocket
    - Cutter: R390-040Q16-17M
    - Insert: R390-170431M-PM 1025

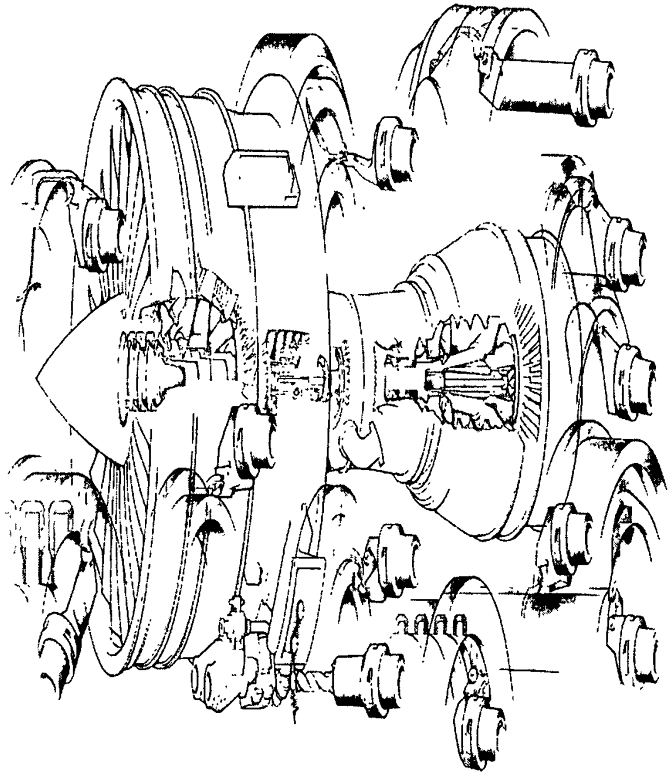
附件五、超合金加工刀具與參數選用
(SANDVIK 測試報告)

Welcome
to
the segment
Gas Turbines

SANDVIK Coromant

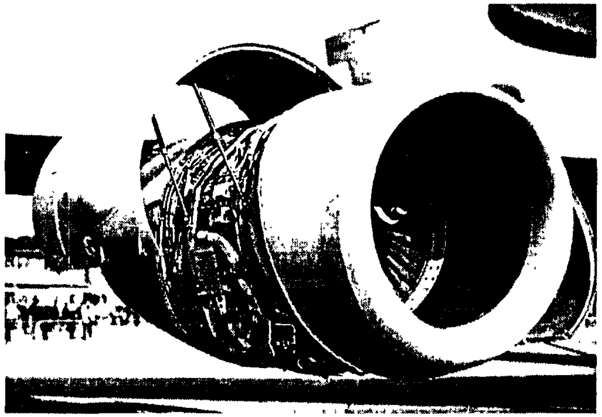
Gas Turbine focus,

HRSA & Titanium



- Continuous research on tools for high productivity & reliable machining
- Acting on customer demands with projects and partner ship
- Engineering capacity, TM options and a competitive special tool supply

SANDVIK Coromant



Front

End

Solutions for:

- Inlet Duct
- Compressor
- Combustion Chamber
- Turbine
- Exhaust Duct

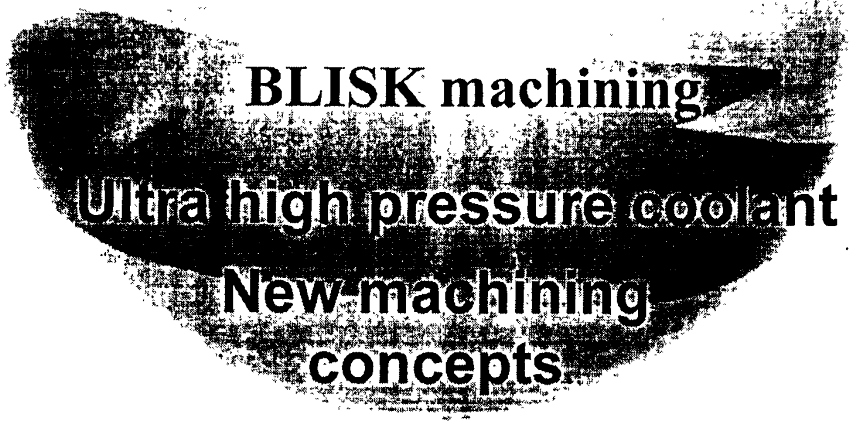
SANDVIK Coromant

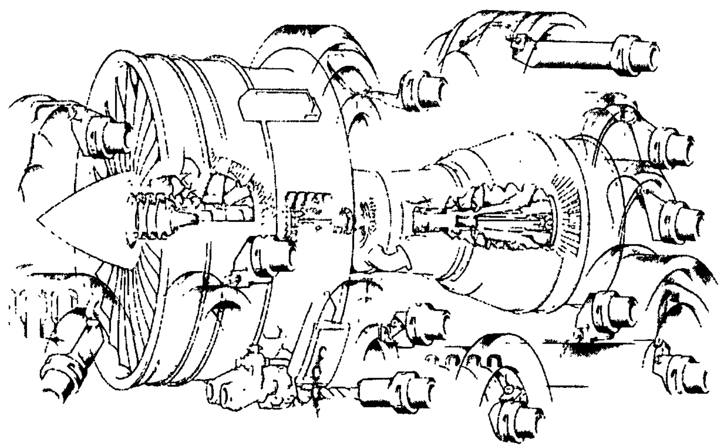
Gas Turbine machining trends

Increase of titanium alloys

Grades for higher speeds:

- Coated
- Ceramics





Gas Turbines

- Manned aircraft / aerospace
- Industrial & Marine Gas Turbines
- APU / GPU
- Missiles / Drones

SANDVIK Coromant

Gas Turbine Engineering support

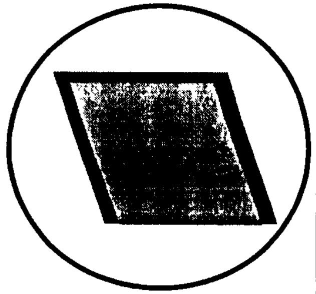
- Performance testing
- Cutting data recommendations
- Developing methods for cutting
- Develop engineered special and or recommendations of standard tools
- Simulate machining of parts in our own workshop / calculations (FEM)

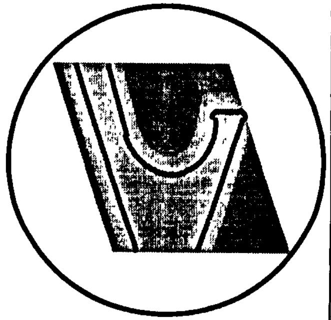
SANDVIK Coromant

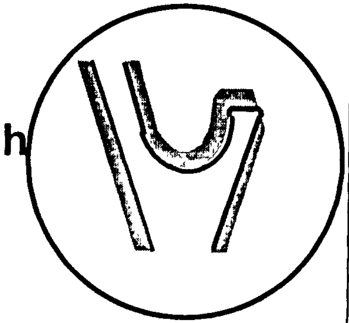
Aerospace engine

Machining Areas

FSM	First stage machining	0 to 10mm depth of cut Removal of forged/cast scale. Ovality and interrupted cuts
ISM	Intermediate stage machining	0.5 to 4mm depth of cut Shaping Varying depths of cut Moderate tolerances
LSM	Last stage machining	0.2 to 1mm depth of cut Finish shape High tolerances/surface finish







SANDVIK Coromant

Aerospace engine - materials

Material Properties

- **Titanium** - Used in the compressor
  - high weight to strength ratio.
  - Used up to 538 deg C
- **HRSA** - Used in the combustion/turbine
  - High corrosion resistance
  - Retain their hardness and strength at higher temperatures. Used between 540 to 1000deg C
  - Hardenable

Other industry sectors - power generation, oil, petrochemical and medical

Aerospace engine - materials

HRSA Material conditions

Method	*Components*	*Reason*
Forging	-discs, casings	basic shape and for strength
Castings	-blades, spacers/rings	low strength - near net shape
Bar stock	-shafts, small dia parts	bought straight from producer

Machinability

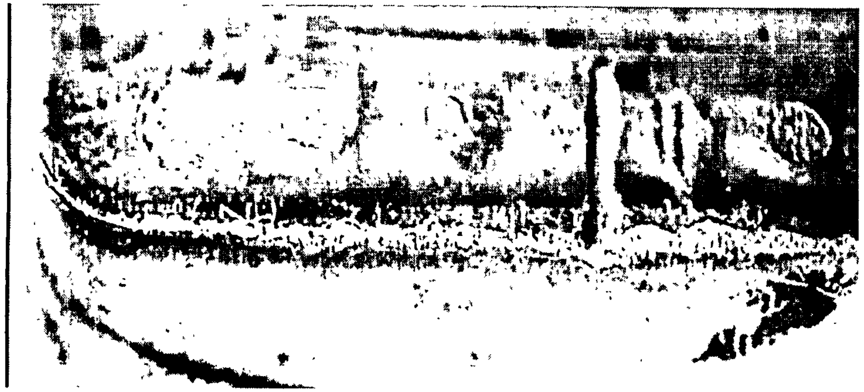
good ⟷ *bad*

Condition - bar stock ⟷ forgings castings

Hardness - soft ⟷ hard

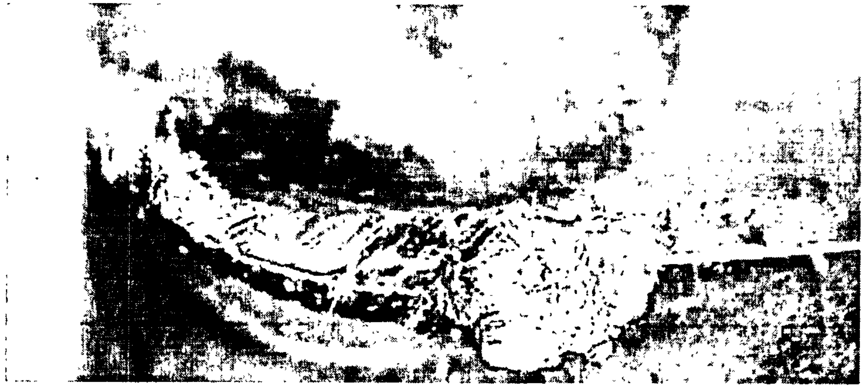
SANDVIK Coromant

WEAR PATTERNS MACHINING HRSA



FIRST STAGE MACHINING
Material hardness - 26HRC/270HB
1005 speed range - 30 to 40m/min

Wear types - uneven flank
plastic deformation
crater



INTERMEDIATE STAGE MACHINING
Material hardness - up to 46HRC/440HB
1005 speed range - 40 to 70m/min

Wear types - notch (*Kr, radius, ap)
crater

LAST STAGE MACHINING
Material hardness - up to 46HRC/440HB
1005 speed range - 60 to 80m/min

Wear types - even flank
plastic deformation
crater

SANDVIK Coromant

WEAR PATTERNS MACHINING HRSA

Plastic Deformation/ even flank wear

- Combination of high temperatures and high pressure on the cutting edge.
- Grades require good wear resistance and hot hardness.

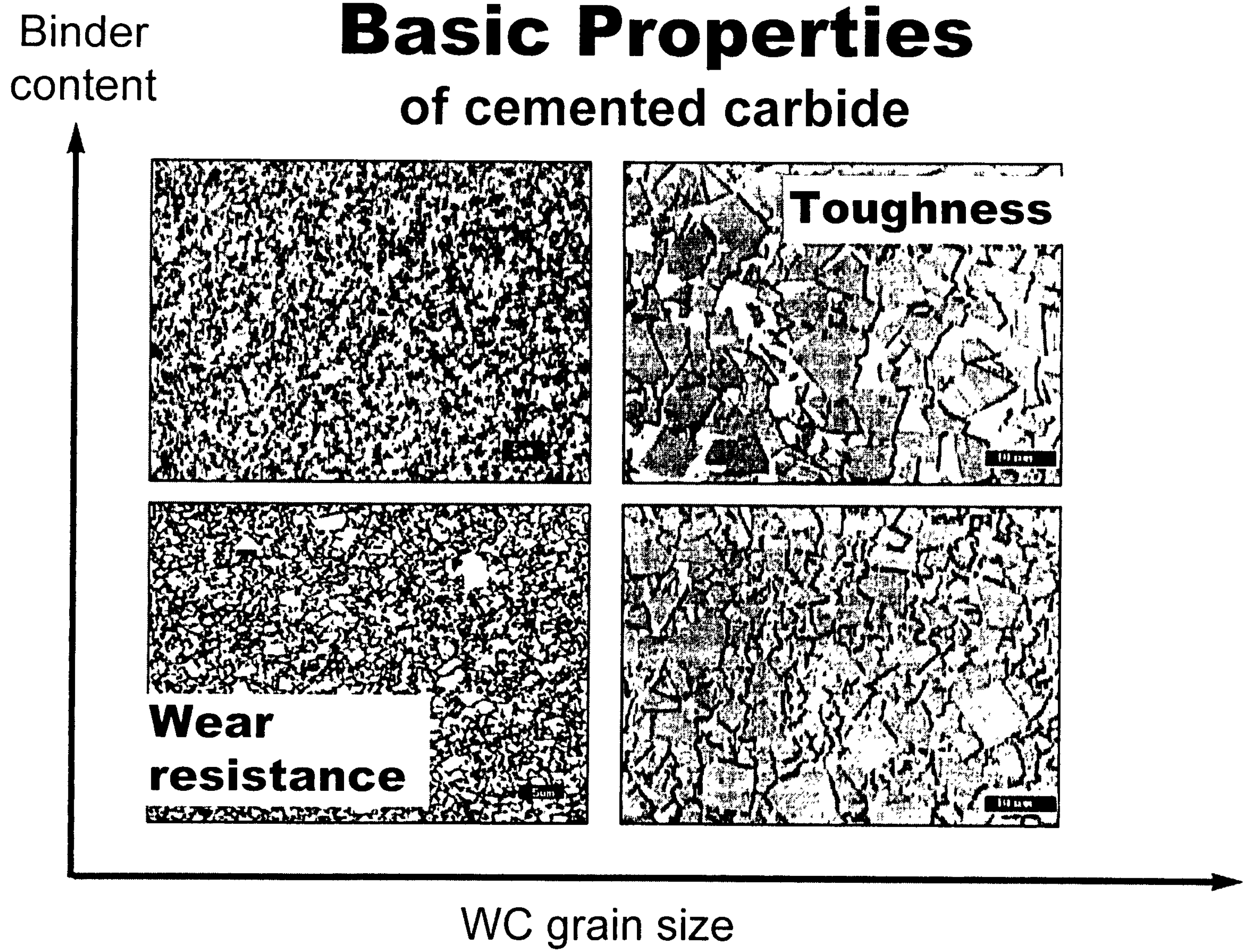
Wear resistance ↑

- Sialon ceramic
- Whisker ceramic
- CVD carbide
- PVD carbide
- uncoated carbide

SANDVIK Coromant

Basic Properties

of cemented carbide



SANDVIK Coromant

WEAR PATTERNS MACHINING HRSA

Notch Wear

	Least +			- Worst
Material hardness	soft			hard
Material condition	bar stock			forged/cast
Approach angle	45deg	75deg		95deg
Depth of cut	below radius/round			over radius
Insert Geometry	positive			negative
Insert Grade	PVD carbide		CVD carbide	ceramic

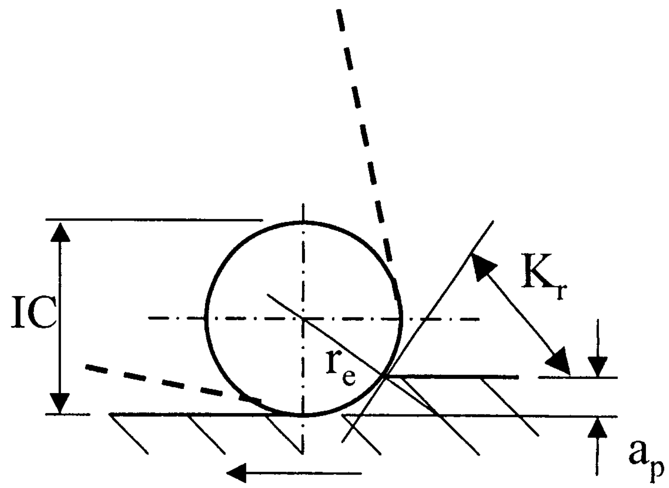
SANDVIK Coromant

ROUND INSERTS IN HRSA

Entering angle

The entering angle varies with round inserts depending upon the ratio of a_p to IC.

Depth of cut to diameter ratio ap/IC	Depth of cut for insert size				Entering angle Kr
	8	10	12	16	
0.25	2	2.5	3	4	60
0.2	1.6	2	2.4	3.2	53
0.15	1.2	1.5	1.8	2.4	46
0.1	0.8	1	1.2	1.6	37
0.05	0.4	0.5	0.6	0.8	26



$$\cos K_r = 1-2(a_p/IC)$$
$$= 1-(a_p/r_e)$$

Max a_p 0.25 IC

Best performance lower than K_r = 45deg - a_p 0.15dia

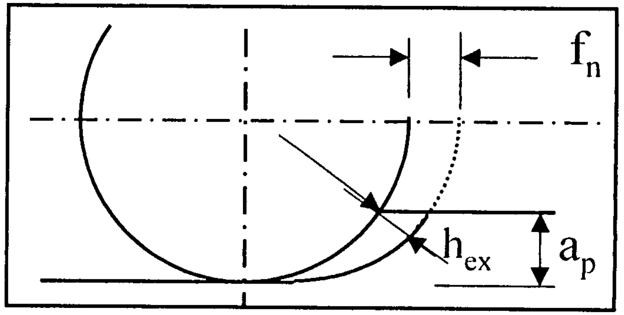
SANDVIK Coromant

ROUND INSERTS IN HRSA

Chip thickness

The chip thickness varies with round inserts depending upon the entering angle. The feed rate can be increased at lower depths of cut.

Depth of cut to diameter - ap/IC	Entering angle Kr	Feed modifaction value
0.25	60	1.16
0.2	53	1.25
0.15	46	1.4
0.1	37	1.66
0.05	26	2.3



$$f_n = \frac{hex}{\sin K_r}$$

Chip thickness	Min	Max
Ceramic	0.08	0.15
Carbide	0.1	0.4

SANDVIK Coromant

ROUND INSERTS IN HRSA

Surface finish

The surface finish is a direct relationship between nose radius and feed rate. To achieve a set surface finish a higher feed rate can be used with a large radius insert.

Maximum feed to achieve surface finish Rmax 8.0, Ra1.6um, N7							
Nose radius size				Insert diameter			
0.4	0.8	1.2	1.6	8	10	12	16
0.17	0.22	0.27	0.32	0.5	0.57	0.62	0.7

SANDVIK Coromant

Aerospace engine

Ceramic Grades for HRSA

CC670 -	**Whisker ceramic - excellent toughness making it most suitable for high feed and more unstable applications**
CC6080 - **(CP02.1)**	**Sialon ceramic - excellent notch resistance but with reduced toughness compared to CC670**

For roughing - ceramics performance is best with K_r less than 45deg

- **Round inserts with ap below 0.15D**
- **Square inserts 45deg approach where larger cuts are required**

Modify feed depending upon the approach angle

Chip thickness between 0.1 to 0.15mm is optimal

SANDVIK Coromant

Aerospace engine

Carbide Grades for HRSA

1005 - **PVD coated (TiAlN) fine grain carbide with good hot hardness and toughness. It works in all application areas combined with QM geometry for high feeds and -23 geometry for lower feeds.**

S05F (CP02.1) - **CVD coated fine grain carbide developed for LSM and other PD demanding operations. Excellent hot hardness and coating adherence gives predictable tool life for both high and low cutting speeds.**

SANDVIK Coromant

FINISHING WITH 1005

INCONEL 718 AND WASPALLOY

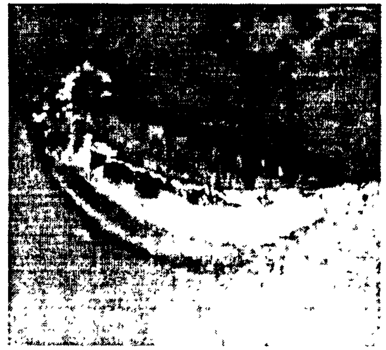
AP-0.5mm, F0.25mm/rev
CNMG 120412 QM

Vc50m/min
1 pass - 6'32"

Vc70m/min
1 pass- 4'42"

Vc80m/min
1 pass - 4'06"

Vc90m/min
1 pass - 3'38"

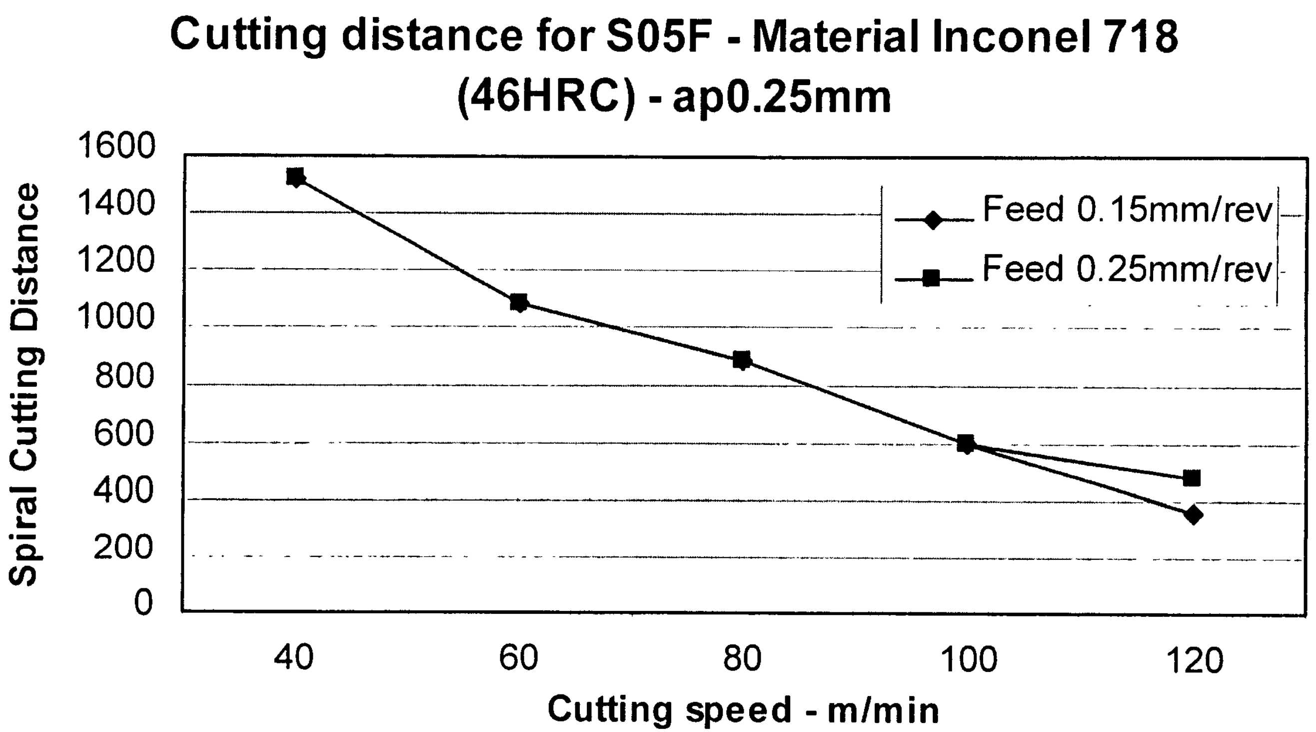


Vc - too low
Smearing of workpiece to coating. Coating flaking will occur giving poor tool life

BEST WORKING AREA 60-80m/min
Even flank wear with minimal smearing. The notch and flank wear increases with the speed.

Vc - too high
Rapid flank wear plastic deformation and depth of cut notching due to high temperature

Tool life with S05F in Inconel 718 (46HRC)



	Feed 0.15mm/min		Feed 0.25mm/min	
vc	mins	cutting length	mins	cutting length
40	38	1520	38	1520
60	18	1080	18	1080
80	11	880	11	880
100	6	600	6	600
120	3	360	4	480

SANDVIK Coromant

Selecting surface cutting speed for finishing with S05F - using Spiral Cutting Length (SCL)

- S05F has a predictable tool life characteristic.
- Each feature on a component requires different contact times
- The contact time to machine a distance on a given diameter changes depending upon the feed/rev
- with S05F we recommend that the total length of cut is calculated and then a corresponding speed is used to maximise productivity.
  - *Note feed rate effects the SCL but not the contact time to reach a set wear criterion.*

SANDVIK Coromant

Calculating <u>S</u>piral <u>C</u>utting <u>L</u>ength for finishing with S05F

$$SCL = \text{Circumference} \times \frac{\text{Length of cut}}{\text{feed rate}} = \frac{D*\pi*L}{1000*f_n}$$

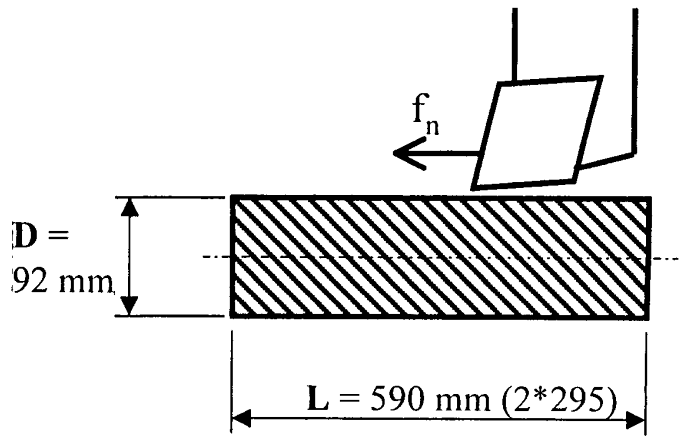
Example: finishing cut at D=92mm and L=590mm

Feed 0.25mm/rev

SCL = [(92/1000) x 3.142] x (590 / 0.25)
= <u>682 m</u>

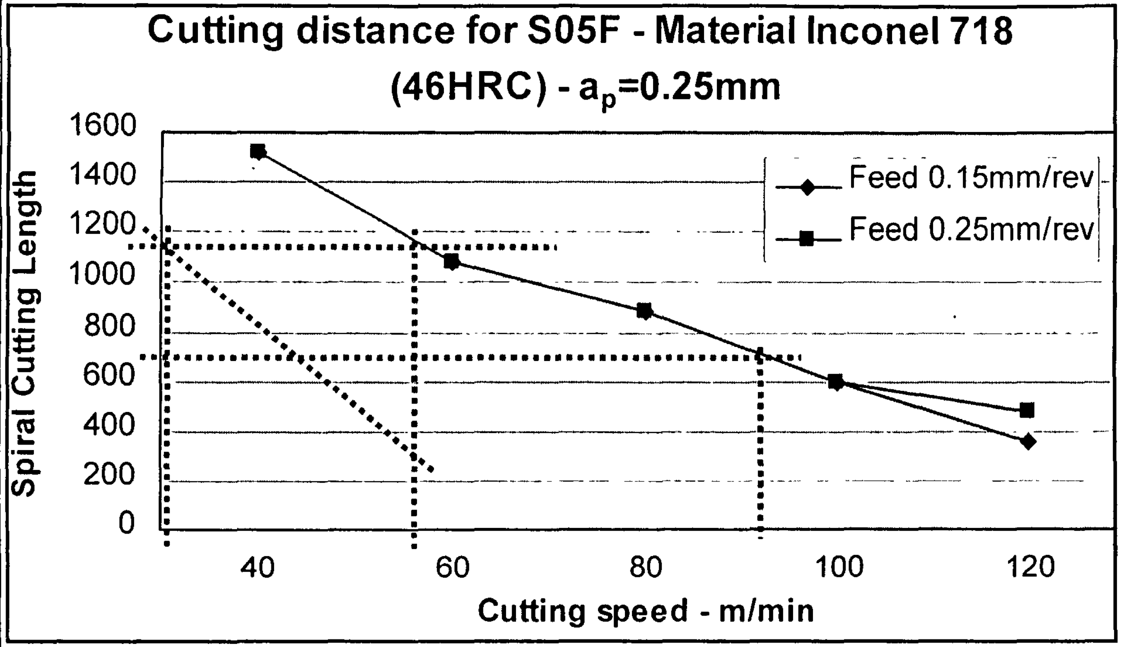
Feed 0.15mm/rev

SCL = [(92/1000) x 3.142] x (590 / 0.15)
= <u>1136 m</u>



SANDVIK Coromant

Finding optimized speed with grade S05F



Feed 0.25mm/rev with S05F

SCL = 682m (for 590mm cutting length)

Best productivity achieved at approx 90m/min - Time to machine - 7.6 mins

Feed 0.15mm/rev with S05F

SCL = 1136m (for 590mm cutting length)

Best productivity achieved at approx 55m/min - Time to machine - 20.7 mins

(compare **uncoated** grade at Vc = **30m/min**, f_n = 0.15mm/r ⇒ **37.9 mins**)

SANDVIK Coromant

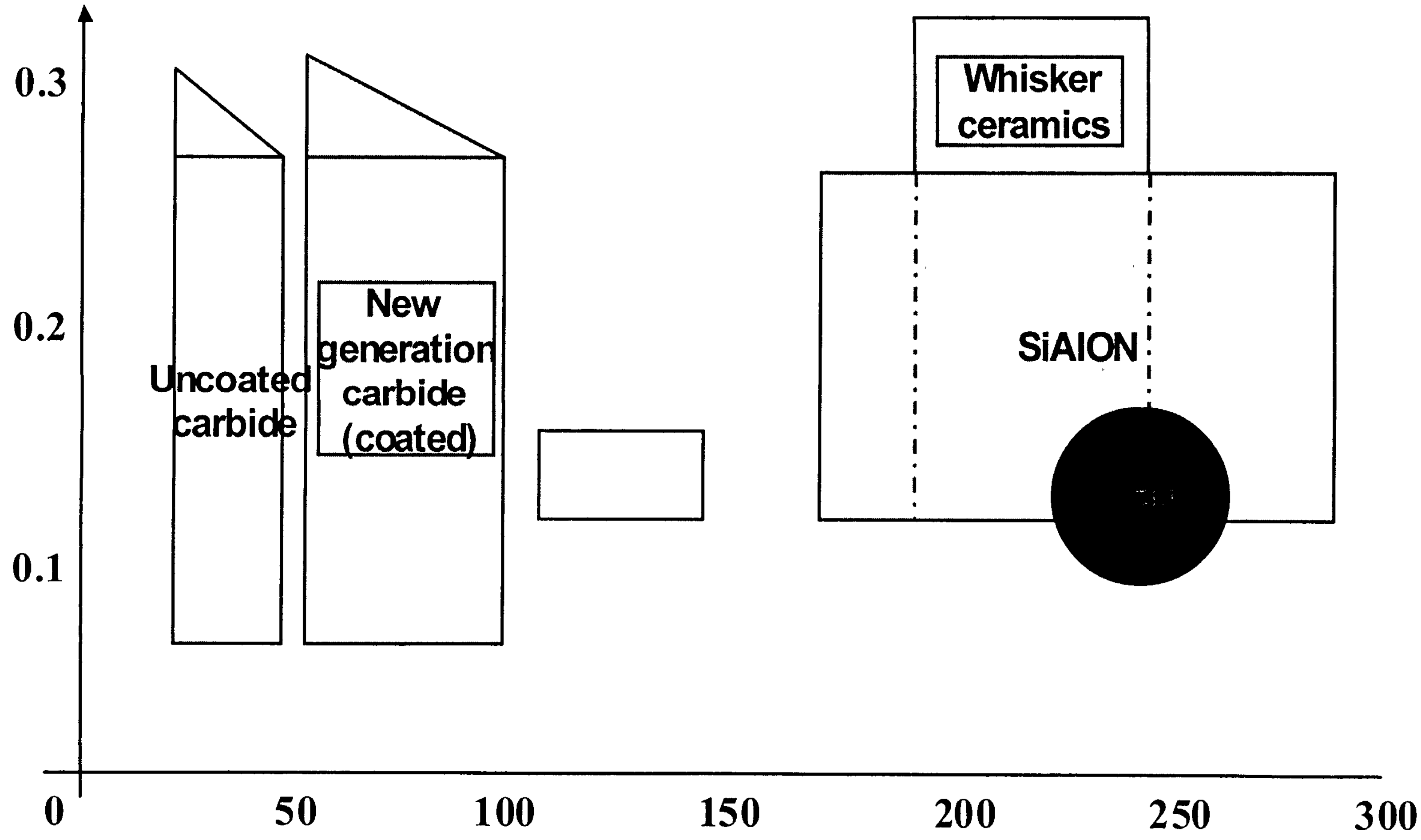
Aerospace engine

HRSA MACHINING

Machining stage	1st choice	2nd choice
FIRST	**GC1005**	**Whiskered ceramic 670**
INTERMEDIATE	**Ceramic 670 (whiskered/SiALON)**	**GC1005**
LAST	**S05F**	**CBN 7020/7050**

SANDVIK Coromant

Cutting tool materials
Application Area for HRSA



MTU visit.ppt

Aerospace engine - Titanium

Characteristics	Grade requirements
High heat generated	Hot hardness
High forces generated on a small area	Edge line toughness
Chemical crater wear	Abrasive resistance Uncoated

Fine grained, low Cobalt, uncoated - H10, H10A, H13A - H10F

SANDVIK Coromant

Aerospace engine - Titanium

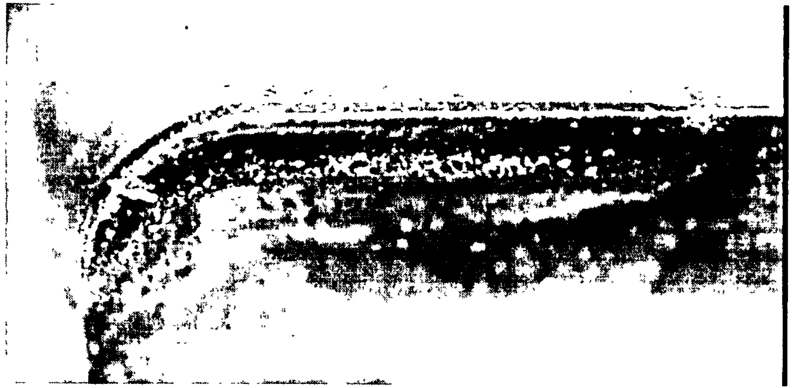
Characteristics	Geometry requirements
Chemical crater wear	positive geometry - producing minimal friction between chip and rake face
Thin chip thickness/ highly sheared chip	positive micro geometry primary land max 0.5xfn
High forces generated on a small area	Lower than normal feed

SANDVIK Coromant

WEAR PATTERNS MACHINING TITANIUM

FIRST STAGE MACHINING
speed range - 30 to 40m/min

Wear types - uneven crater
notch
flank



INTERMEDIATE STAGE MACHINING
speed range - 40 to 80m/min

Wear types - crater
flank
plastic deformation

LAST STAGE MACHINING
speed range - 60 to 100m/min

Wear types - crater
flank
plastic deformation

SANDVIK Coromant

Aerospace engine

TITANIUM MACHINING RECOMENDATIONS

Machining stage	Insert style	Grade	Speed m/min	Feed mm/rev	DoC mm	Comments
FSM	SNMG 190616 QM CNMG 190616 QM TNMG 27**16 QM	H13A	30-40	0.3-0.4	up to 10	use SNMG - 45deg approach to reduce chip thickness where possible - max number of edges
ISM	CNMG 120412-23 SNMG 120412-23	H10A	50-70	0.15-0.25	up to 5	Normally component dictates insert style, use max nose radius for best tool life
	RCHT 1606MO-KL RCHT 1204MO-KL	H13A	60-80	0.3-0.4	up to 3 up to 4	Round inserts give the highest productivity where component allows their use.
LSM	CNGP 120408 CCGX 120408-AL	H13A	80-100	0.1-0.2	0.25 to 1.0	*NGP/AL micro geometry optimised for Titanium finishing
	RCHT 1204MO-KL RCGX 10T300-AL	H13A H10	80-100	0.2-0.4 0.2-0.3	0.25 to 1.0	Round inserts give the best productivity and surface finish where components allow their use.