行政院及所屬各機關出國報告
（出國類別：考察 ）

（航空致動器技引案—
直流無刷馬達第一階段技轉落實訓練）

服務機關：中山科學研究院
第一研究所
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姓　　名：謝福汴
職　　稱：中校技正
姓　　名：楊定一
職　　稱：薦聘技士
姓　　名：吳嘉穎
出國地區：美國芝加哥
出國期間：89.09.16 至 89.09.25
報告日期：90.01.02

目　錄

壹、出國目的及緣由

本次公差係依據本所執行經濟部科專『航空致動器技術引進』計畫，主要目的係依計劃需求，執行航空致動器設計、製造、組裝、檢驗、測試及品質系統之雛型試製與實作示範之技術移轉，另亦爭取與 MPC 公司合作共同開發它型航空致動器系統關鍵零組件，以配合政府推展航太工業政策。為能爭取合作機會及提昇技術與擴散科專成果，由簡聘技監謝福汴、楊定一中校及吳嘉穎技士等三員赴美國 MPC 公司，以技轉學習設計、製組、測試及品質系統等技術，並搜集先進關鍵技術資料文件、借以落實引進技術本土化深根及尋求擴展國際市場商機相關事宜，以最終促使達成科專航太產業昇級效益。

一、本次國外差旅主要任務內容簡述如下：

1.赴美國 MPC 公司，以執行航空致動器設計、製組、測試及品質系統等技術移轉訓練。

2.赴美洲地區搜集相關致動器及伺服馬達與驅動器先進關鍵技術文件。

3.協同 MPC 公司共同拜訪航空致動器系統供應主要計劃、以瞭解及先期研商合作計劃事宜。

4.赴美洲地區尋求致動器等國際市場商機擴展及衍生

應用計劃洽談。

二、本次國外差旅主要工作目標簡述如下：

1.完成 MPC 公司航空致動器引進設計、製組、測試及品質系統技術移轉訓練。

2.完成美洲地區國家相關致動器及伺服馬達先進關鍵技術資料文件搜集。

3.完成與美國 MPC 公司就航空致動器系統供應計劃先期計畫細節洽談。

4.完成美洲地區國家致動器及伺服馬達國際市場商機擴展及衍生合作計劃洽商。

貳、公差心得

一、美國芝加哥之MPC公司簡介

MPC 公司係一國際著名且擁有良好市場營銷業績及產品信譽之業界，該公司成立於1962年，位於美國芝加哥史玫基(SKOKIE)近郊，MPC 公司有 7 個廠房，員工人數超過 750 人，佔地面積約 337,000 平方呎，她有五條生產線—馬達、電子、位移感測器、致動器、飛操連桿控制，目前以生產電機致動器系統(electromechanical actuation systems)為主要經營業務。

MPC 公司之經營理念，就業務而言係以掌握客戶及市場需求為要件，另就工程而言係以掌握核心研發設計之專精知能(KNOW-HOW)為主，而部份實際製造工作，考量成本因素及效益，則選擇委製於低價且符合品質標準之次合約商執行，但最終組裝及系統測試工作，則自行負責完成；此無疑將是國內工資高漲且勞工短缺情況下，可以學習之榜樣之一。

二、國外訓練重要技術交流項目

本次國外訓練，主題包含：

1.MPC 公司 7 個廠房，由總裁親自帶領至每一個廠房逐一解說介紹。

2.直流無刷馬達(含煞車器)製程細部解說及工廠實際

觀摩攝影。

3.MPC 公司程序之 ISO 相關文件逐一解說。

4.MPC 公司產品展示。

三、電機伺服致動系統技術發展趨勢分析

1.航空電機伺服致動系統應用趨勢分析

經與受訪之 MPC 公司之工程技術及營銷業務部門之主管研討後，歸納出未來航空器電機伺服致動系統應用發展趨勢如下：

(1)高可靠度之整體性能提昇，諸如：智慧型功能、整合型功能、模組化功能等。

(2)可量化技術之指標衡量標準，諸如：高控制精準度、高出力密度、高能源節省指標等。

(3)先進航空器主要線傳飛行控制(Fly-By-Wire)翼面操縱系統。

2.蒐集資料彙整(本所已留存)

(1)MPC 公司產品型錄。

(2)直流無刷馬達之零件製造圖(53 份)、工程指導(27 份)、組裝零件清單(1 份)、施工程序書(12 份)、材料規範(19 份)等(電子檔及紙本檔)。

(3)MPC 公司之 ISO 全部文件資料，共 131 份(電子檔)。

四、綜合觀感

美國芝加哥之 MPC 公司受訓所得的觀感如下：

1.以企業的規模來看，MPC 公司是高科技之中小企業，員工人數超過 750 人，她的七個工廠可以提供完整的研究、工程、製造、最後組裝、合格測試、銷售和客戶支援。

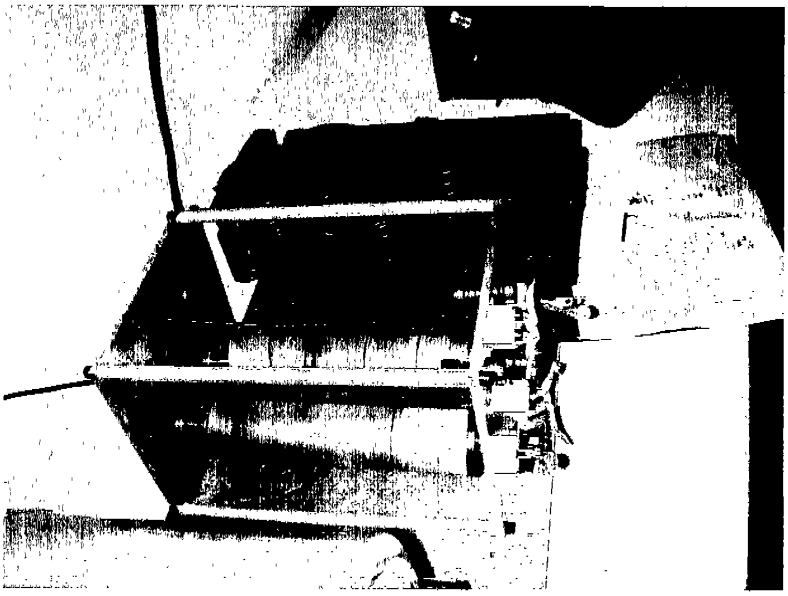
2.MPC 公司有很好的企業文化，從會客室、會議室、辦公室的設計裝潢以及從公司老闆與員工的交談中，可以看出彼此之間坦誠關懷及和睦融洽的氣氛。公司老闆都採取 OPEN DOOR 的政策，員工很容易見到老闆，老闆對待員工也像兄弟姊妹一樣，這樣的文化對公司的創新及產能都有加乘的效果。

3.MPC 公司是典型的中小企業，但她卻很能掌握競爭優勢；第一：她能掌握關鍵技術及品質系統。其次：她的外包政策及夥伴關係遍及亞洲、歐洲，充份利用公司外在資源，以創造低成本的優勢。第三：她不斷的創新精進，使其產品在市場上維持佔有率。若從競爭優勢的五個條件，即(1)低成本、(2)高品質及服務、(3)靈活性、(4)獨立性(掌握關鍵技術)及(5)創新精進等五項來評定 MPC 公司，她可以得到高分。再從管理及經營策略的觀點來看， MPC 公司有

很多地方是值得我們學習的。

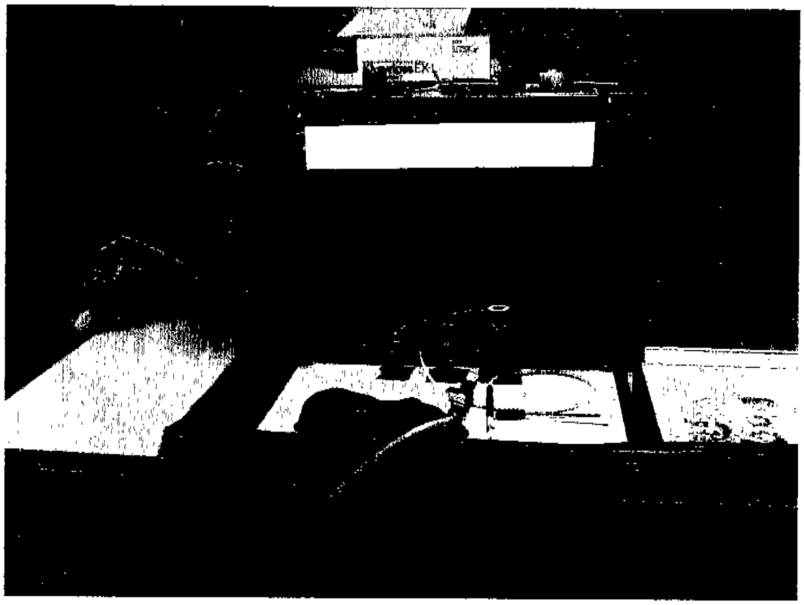
4.本次學習到的主要關鍵技術—矽鋼片堆疊塗膠技術、熱塗抹及靜電塗抹技術、外徑及內徑研磨技術、安裝墊片時之間隙調整技術。

附圖一、上課研討情況

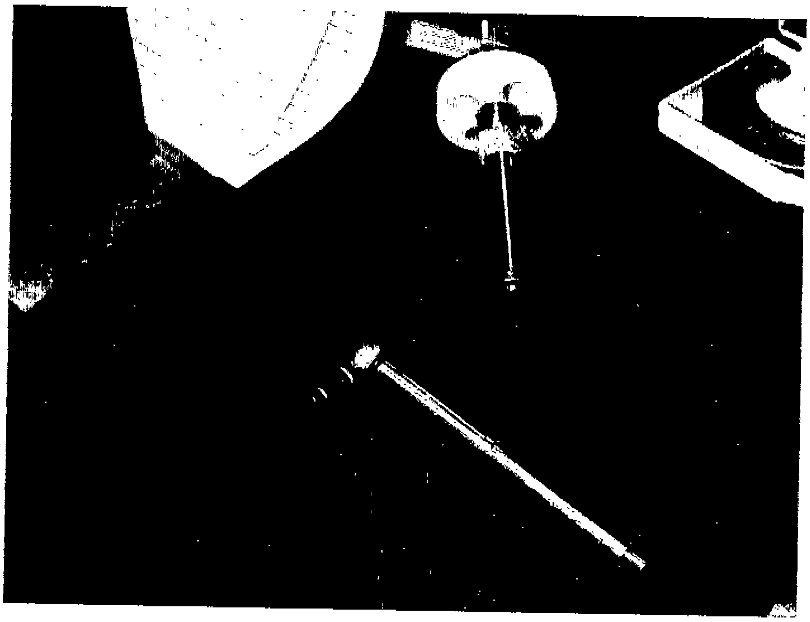


附圖二、矽鋼片清洗治具

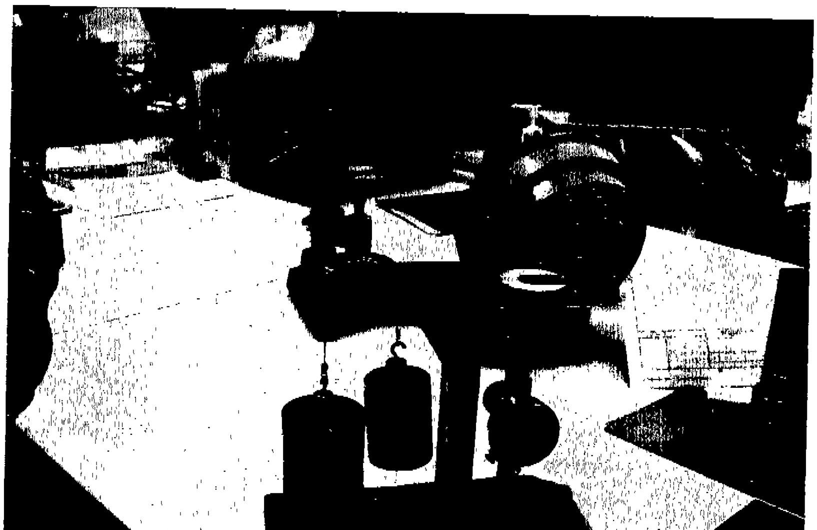
附圖三、矽鋼片堆疊治具



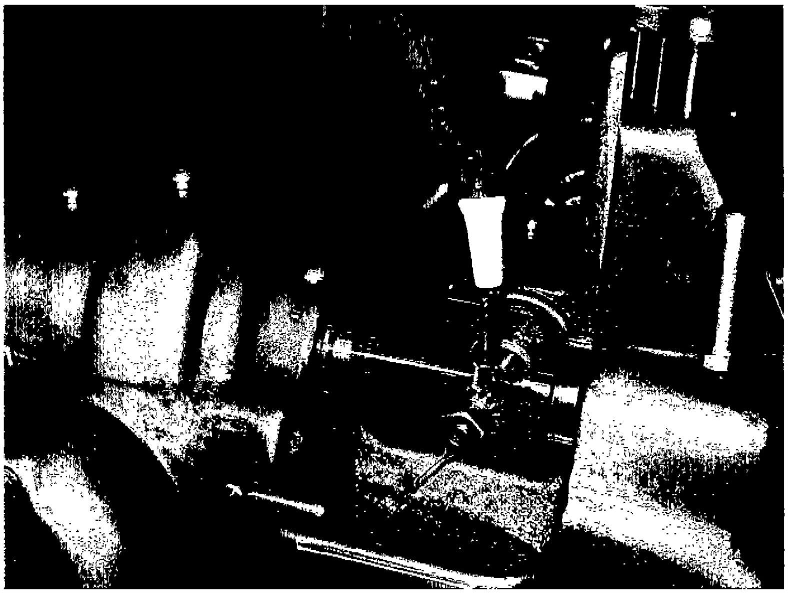
附圖四、靜電塗抹治具



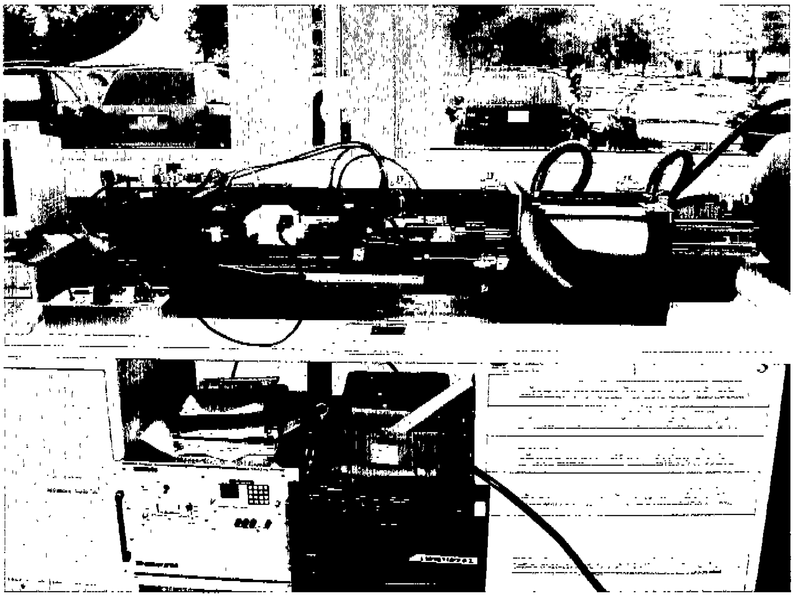
附圖五、外徑研磨夾治具



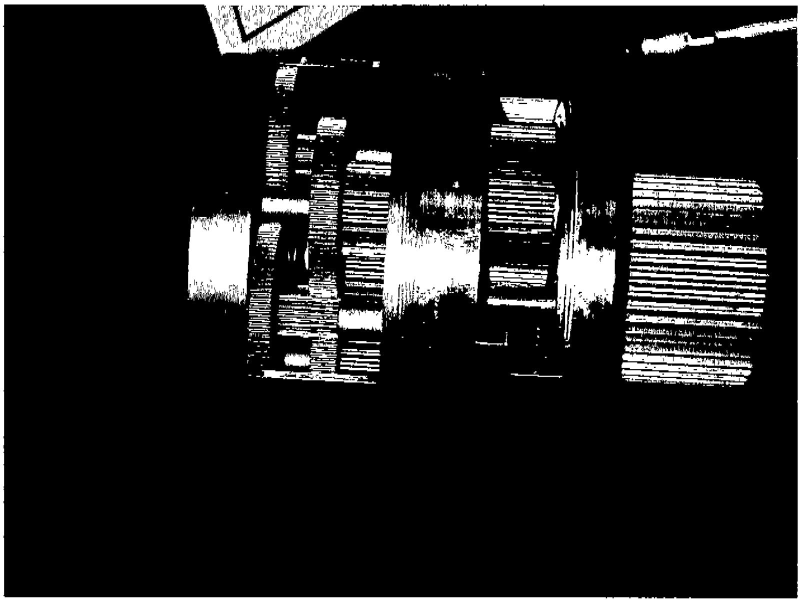
附圖六、安裝墊片(SHIM)之量測調整治具



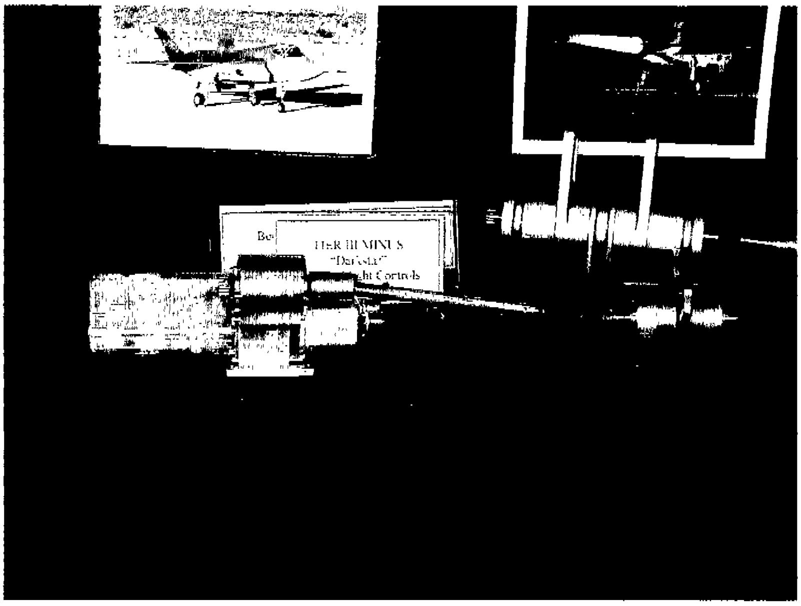
附圖七、齒輪加工機



附圖八、致動器測試裝備



附圖九、差速齒輪箱樣品



附圖十、致動器及連桿樣品

參、效益分析

本次國外差旅之整體性計劃效益，藉由本次受訓結果，可得具體結論如下：

本所與美國芝加哥之MPC公司就經濟部航空致動器技術引進科專案—執行航空致動器設計、製組、測試及品質系統等技術移轉訓練，進行工廠實做觀摩研討。

就矽鋼片堆疊來說，目前國內廠商製造方法是每片矽鋼片塗膠，一片片堆疊，組裝完成經過烘烤後，還須花費很長的時間去除內槽多餘的膠料，每日只能生產幾個。而MPC公司生產前將治具設計製造完成，矽鋼片清洗後，將矽鋼片全部堆疊後才塗膠，內槽幾乎沒有多餘的膠料，每日可以生產幾十個。

就靜電塗抹來說，配合承接廠商六俊公司，目前已在採購類似此種靜電塗抹裝備中，在此次學習已先行學到如何操作之技巧。

就墊片安裝來說，目前國內廠商製造方法是一片片的安裝，又拆又裝，不斷的測試，既不科學又浪費工時。而MPC公司是先依據施工程序書的規定裝上墊片，再放在測試量具上，看數據調整應改為何種厚度

之墊片，每位作業員邊均有一個裝有各種厚度墊片的盒子，如此可節省工時。最重要的是在墊片前端放一片波浪型墊片以控制軸承安裝的間隙，此點是國內廠商新學到的技術。

類似此種可節省工時、節省成本、增加產能技術移轉還有很多項，在此無法一一敘述。總而言之，MPC公司是非常值得我們學習的對象。

肆、國外工作日程表

日期	星期	工作日程
09/16	六	由台中出發到桃園搭機；至美國洛杉磯入關
09/17	日	由洛杉磯轉機至芝加哥及廠商安排連繫&資料整理
09/18	一	MPC 公司技術訓練(詳如續頁)
09/19	二	MPC 公司技術訓練(詳如續頁)
09/20	三	MPC 公司技術訓練(詳如續頁)
09/21	四	由芝加哥轉機至紐約及廠商安排連繫&資料整理
09/22	五	MPC 公司實習(總部)
09/23	六	MPC 公司工程研討會及計劃審查
09/24	日	由紐約轉機至洛杉機拜訪 MPC 公司銷售陳列中心
09/25	一	返國飛行。

中山科學研究院出國人員工作計劃表(續)

級職	姓名	日期	工作項目	
簡聘技監	謝福汴	89.09.18	管理品質訓練3小時，工程品質訓練3小時	
		89.09.19	業界合作服務品質訓練3小時，國外購案履約品質訓練3小時	
		89.09.20	商機拓展研討6小時	
中校技正	楊定一	89.09.18	定子設計訓練4小時，磁石選用訓練2小時	
		89.09.19	轉子設計訓練3小時，電控界面理論訓練3小時	
		89.09.20	電機機械分析訓練3小時，規範符合特性訓練3小時	
薦聘技士	吳嘉穎	89.09.18	品質系統制度訓練3小時，設計變更訓練3小時	
		89.09.19	製造程序管制訓練3小時，型態文件管制訓練3小時	
		89.09.20	檢驗量測管制訓練3小時，矯正預防措施訓練3小時	

伍、社交活動

本次訓練主要任務為執行航空致動器設計、製組、測試及品質系統等技術移轉訓練及參觀 MPC 公司的銷售陳列中心，所以沒有多餘的時間做社交活動。

陸、建議事項

技術瓶頸之突破，不外乎自行研發及技術引進兩種方式，近十年來，由於冷戰結束及全球經濟與企業體的形成，歐美先進國家紛紛與亞洲地區國家形成策略聯盟，以降低其成本，提高競爭優勢。因此對技術移轉的意願也相對提高，本院可利用經濟部"技術引進科專"策略，一方面提昇國內產業技術層次，同時也可提高本院研發技術能量，然後在回饋到國防科技的運用上。

另與本院二所自行研發技術比較，皆有若干可供參考及互為教學相長之處，故本所已綜整技術文件及錄影帶等相關資料以供分送二所參考。

附件：(本所已留存)

附件一、本所赴 MPC 公司簡報資料。

附件二、MPC 公司之 ISO 全部文件清冊。

(電子檔共 131 個檔案)

附件三、直流無刷馬達(含煞車器)製程說明。

(電子檔共有直流無刷馬達之零件製造圖 53 份、工程指導 27 份、組裝零件清單 1 份、施工程序書 12 份、材料規範 19 份等)

附件四、直流無刷馬達之設計及建構。

附 件 一

Chung Shan Institute of Science & Technology
Aeronautical Systems Research Division

Program Title：Licensed Technology Transfer of Aerospace Actuation Control Technology

Program Status Review

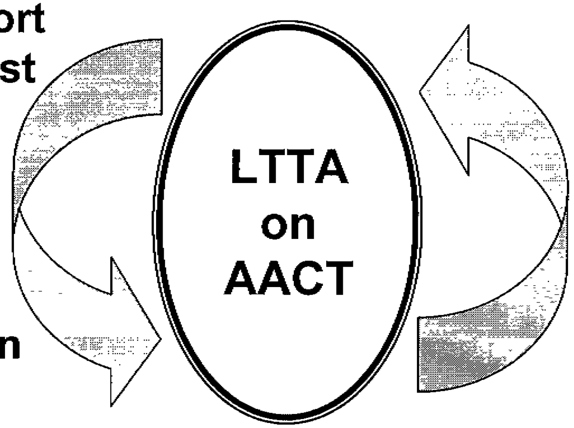
Prepared By：CSIST/ASRD
Date：September 18, 2000

Table of Contents

1.Win-Win Program

- Licensed Technology Transfer
- System/Components Manufacturer

- OEM Production Support
- Interchange of Low-Cost Mass Production Technology
- Establishment of Supplier and Production Support Chain
- Regional Customer Close-in Logistic Support

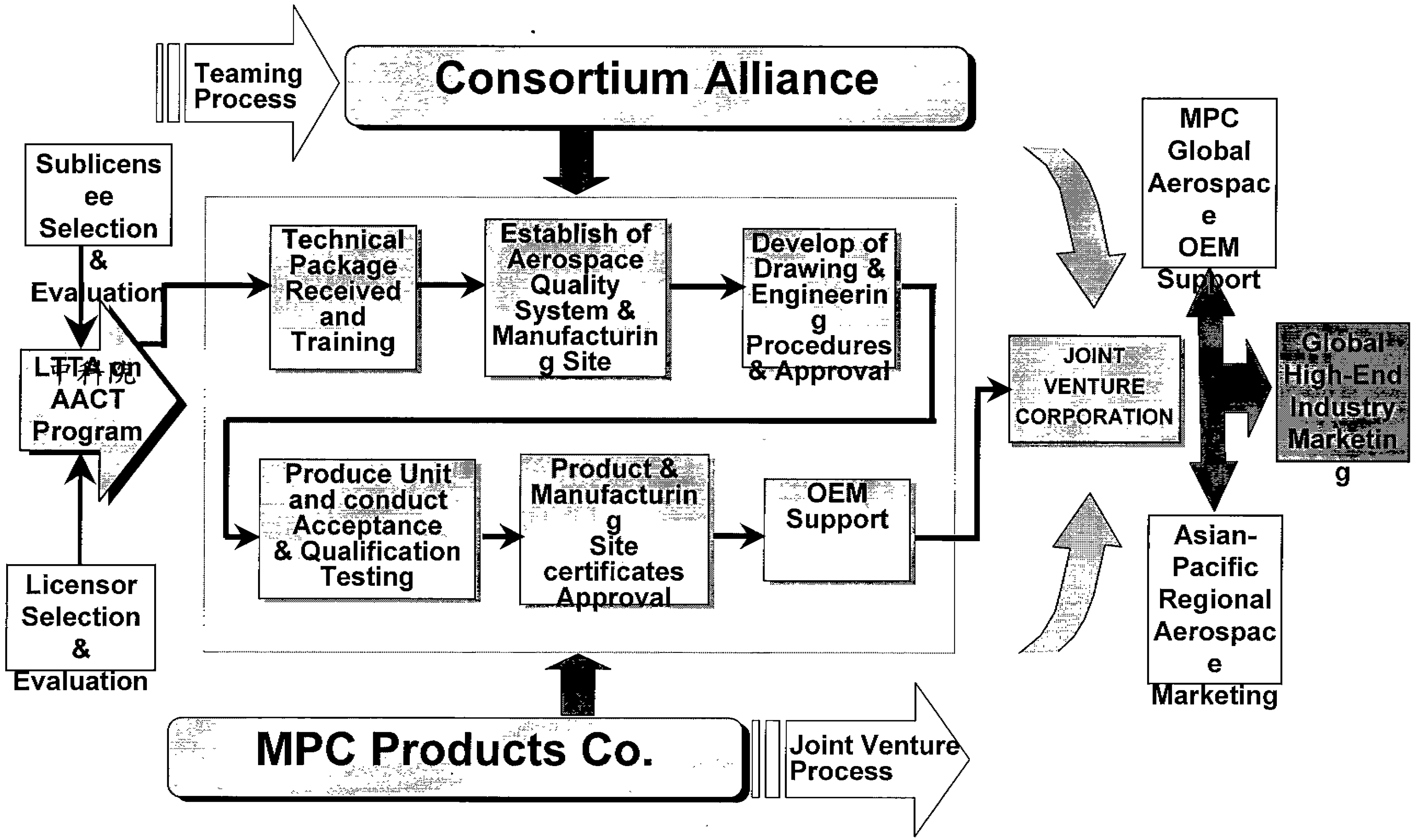


- High-End Industrial Market Capture
- Broadened Technology Application
- Toward Global Aerospace Market
- Toward Global High-End Industrial Market

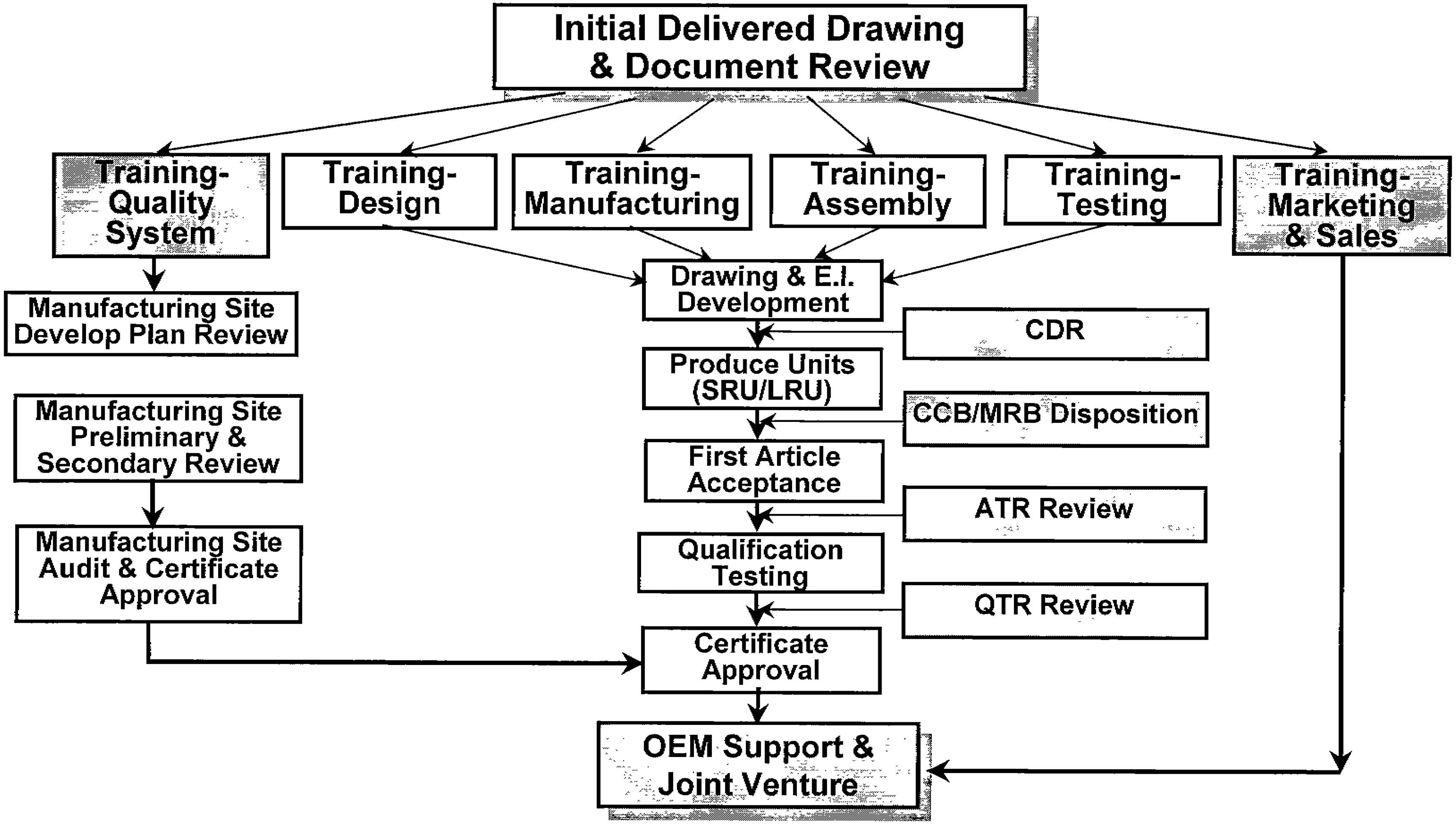
- In-Country Consortium Alliance
- International Joint Venture

AACT Program Strategic Planing Objectives

2.LTTA Procedural Overview



3.AACT Training Flowchart



4.Program Status

1.MPC and ASRD had signed contract on the transfer of Aerospace Actuation Control Technology (AACT) by 04/27/00’, with effective period starts from 05/01/00’ till 06/30/02’.

2.MPC had delivered phase I Technical Package on 06/16/00’, and Initial Design and Manufacturing Review held and completed on 06/21/00’(Contractual Requirement per Step 1 & 2 of Attachment C on Phase I).

3.MPC had also completed the Manufacturing Flow Plan Review (Contractual Requirement per Step 3 of Attachment C on Phase I) and the Preliminary Quality System Planning Review on 06/22/00’.

4.Program Status

4. ASRD had and MPC had reached agreements to accelerate the AACT program by starting Phase II from 10/01/00' and Phase III from 01/01/01'(See Note below) to fuel future OEM support capability in time for Consortium.

   Note:MPC had promised delivery of Phase II Technical Package before 09/15/00'.

5. ASRD had provided responses to MPC commented draft Sub-License Agreement (SLA), pending further discussion on SLA to allow legally bound transfer of AACT to Consortium.

6. ASRD had submitted MPC with Contract Amendment #1 to implement MOU signed in concurrence with Master LA on 04/27/00', pending, however, official signoff and return.

4.Program Status

7.ASRD had regularly reported MOEA (Funding Agency) on the major activities and progresses of AACT program. Increasing concerns, as expressed by MOEA Controller, concentrated on the apparently exhibited non-adherence to schedule. ASRD suggest MPC to **place elevated efforts to boost the Phase I AACT program** as well.

8.The revised overall program master schedule is depicted as follow;

5.Program Scheduling

LICENSED AEROSPACE ACTUATION CONTROL TECHNOLOGY TRANSFER PROGRAM

-- MASTER SCHEDULE (RESHEDULED & ACCELERATED PROGRAM) --

SEPTENBER 18, 2000

Phase	Task Name \ Year / Month	2000						2001						2002				Remarks
		01-02	03-04	05-06	07-08	09-10	11-12	01-02	03-04	05-06	07-08	09-10	11-12	01-01	03-04	05-06	07-08	
I	**(1)Brushless DC Motor & Commutation Sensor; (MPC P/N:CBF206)**			05/01/2000					03/31/2001									"Trial-Order Parts" shall include components such as Gear(s), Ball or ACME Screw(s), and Precision Machined Part(s).
	(2)Manufacturing Site Development & Approval			05/01/2000					03/312001									
	(3)Selected Trial-Order Parts Manufacturing & Approval				07/01/2000		12/31/2000											
II	**(1)Standard Brushless DC Controller; (MPC P/N: E6D1200X)**					10/01/2000					07/31/2001							
III	**(1)Linear ElectroMechanical Actuator; (MPC P/N: 2A21480201)**							01/01/2001					12/31/2001					

Note: Phase I schedule shall not extend beyond 03/31/01' .

5.Program Scheduling

LICENSED AEROSPACE ACTUATION CONTROL TECHNOLOGY TRANSFER PROGRAM

-- PHASE 1 PROGRAM SCHEDULE (RESCHEDULED) --

- FROM 05/01/2000 TO 03/31/2001 -

SEP. 18, 2000

Phase	Task Name \ Year / Month	2000										2001				Remarks
		03	04	05	06	07	08	09	10	11	12	01	02	03	04	
I	**(1).Brushless DC Motor & Commutation Sensor; (MPC P/N:CBF206)**				▽01			▽02		▽03		▽04		▽05		
	(2).Manufacturing Site Development & Approval				▽06					▽07		▽08		▽09		
	(3).Trial-Order Parts Manufacturing							▽10		▽11		▽12	▽13			

5.Program Scheduling

Major Milestone Check Point on Phase I Program (RESCHEDULED)

Item	Task Description	Forecast Date	Payment Conditions
01	Completion of Design & Manufacturing Review (Phase I)	06/25/2000	Milestone Payment #1
02	Completion of Training Program(at Licensee's Facility)	09/25/2000	Milestone Payment #2
03	Completion of Critical Design Review(CDR)	11/30/2000	Milestone Payment #3
04	Completion of First Article Acceptance Testing	01/31/2001	Milestone Payment #4
05	Issuance Of Certificate on Phase I Product and Initial OEM Order Release	03/31/2001	Milestone Payment #5 & #6
06	Completion of Manufacturing Flow Plan Review	06/25/2000	
07	Completion of Manufacturing Site Preliminary Review	11/30/2000	
08	Completion of Manufacturing Site Secondary Review	01/31/2001	
09	Issuance Of Certificate on Manufacturing Site	03/31/2001	
10	Award of Contract on Trial-Order Part(s) Manufacturing	09/30/2000	
11	Completion of Trial-Order Part(s) Manufacturing Procedure	11/31/2000	
12	Completion of Trial-Order Part(s) First Article Inspection	01/31/2001	
13	Insurance Of Certificate on Trial-Order Part(s) and OEM Order(s) Release	12/28/2001	

6.Advantages Thru Joint Venture

1.Taiwan acquires unique **Geographic Central** location to access to most Asian-Pacific countries, which recognized worldwide as the most potential growth regions in future commercial aerospace business. (Enhanced Logistic Support is also urged for customer service)

2.Successful experience in market **transition and expansion** into China (Sharing same culture, customs and languages).

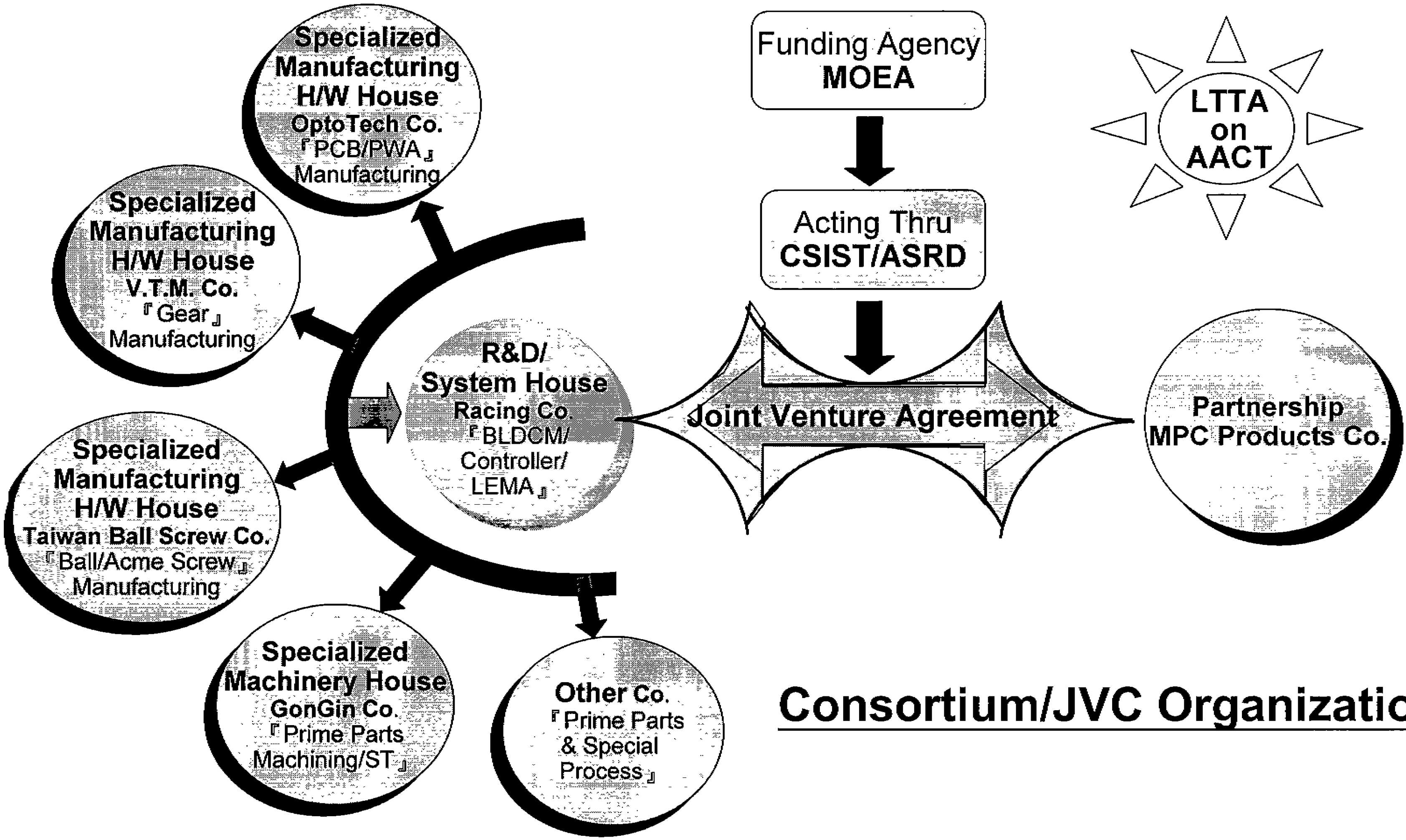
3.Vast experience in cost-controlled production of high quality, large quantity **OEM** parts.

4.Flexibility in **infrastructure** of specialized manufacturing industrial distribution and collaboration system.

5.In-house technology already built-up in a **quasi-ready** state.

6.**Globalisation & Out-source** is well executed policies to maintain competitiveness and enlarge profit.

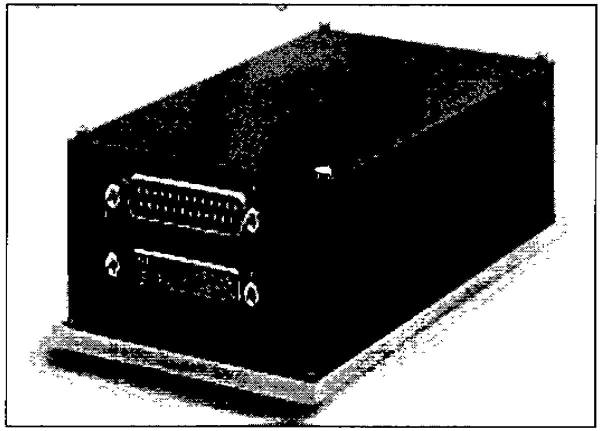
7. Consortium/JVC Organization



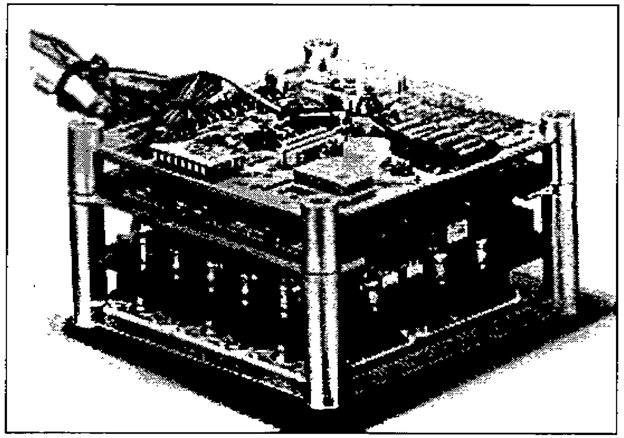
Consortium/JVC Organization

8.ASRD Contribution and Commitment

ASRD committed to incubate and provide Consortium with complimentary technology through Design Center Operation



DSP ServoMotor
Amplifier & Controller



Sensorless DSP
Driver/Controller

Next Generation Motion Control Driver/Controller
-- New Market Capture & Lead in Competition --

9.Open Issues

1. Due to short of supplier source of "superceded" **Military Standards & Specifications**, and experiencing difficulties of obtaining **Industrial Standards & Specifications,** MPC is requested to provide copies to all the related Standards & Specifications for Licensed Products & Trial-Order Parts (as per Article 15.1 & Attachment A) to assist in establishing Consortium's operation-referenced document library.

2. ASRD request MPC to provide referenced copies, or equivalent, of in-house **Quality Policy Manual, Quality Procedure and Quality Instruction** (as per Step 8 of Attachment C), to assist Consortium to properly establish their qualified aerospace Quality System to allow future OEM support to the MPC's commercial aerospace business.

9.Open Issues

3.ASRD request MPC to provide referenced copies, or equivalent, of **Qualification Test Plan and Procedure(s)** (as per Step 11 of Attachment C), to allow Consortium to successfully develop build-to-print package in time for CDR review and approval.

4.As MPC have promised to initiate **Joint Venture Agreement (JVA)**, ASRD suggest MPC to start drafting the JVA with a targeted completion date by **11/30/00'** to provide ASRD/Consortium for review and comments. Also further JVA negotiation shall also be planned through designated meetings to conclude on mutually agreeable principles with a targeted JVA signoff date by **01/31/01'**, and officially execution of JVC formation commencing from **03/31/01'**.

10. JVC e-Commerce at hand

1.As an extension of ASRD's commitment and everlasting service to the JVC, ASRD is now undergo the formulation of a e-Commence project design specifically for the JVC to serve not only to survive in worldwide competition but to broaden her business growth now and in the future.

2.The concept of e-Commence project has already been generally discussed and accepted by both the Consortium and the MOEA. The essence of this project is "**Collaborative Product Commerce(CPC**)", and ASRD has tentatively planned to launch this project at early 2001.

10. JVC e-Commerce at hand

3.Based upon in-house survey of major airframe manufacturer and system supplier in commercial aerospace industry in both US and European, ASRD had perceived that more and more companies had already taken this e-realization process. **ASRD strongly suggest MPC to seriously consider the issue to maintain leading position among increasingly upcoming competition**.

4.The starter approach of ASRD's project is to establish "**Product Data Management(PDM)**"(so called **e-Engineering**), then expand, thru phases, into Enterprise Resource Planning**(ERP)**, Supply Chain Management**(SCM)** and Customer Relationship Management**(CRM)**.

5.A beginner introduction of e-Commerce is described below;

10. JVC e-Commerce at hand

Objective:

To develop a DAMA portal to support collaboration and commerce among JVC's design & manufacturing value chain

Experienced Benefits from Customer Feedback:

- **Faster Time-to-Market (20% - 50%)**
- **Higher Quality (10% - 40%)**
- **Reduced Inventories (15% - 60%)**
- **Increased Ramp Ability for Unexpected Demand (25% - 75%)**
- **Lower COGS (3% - 10%)**
- **Improved RONA (5% - 40%)**
- **Customer Satisfaction (40% - 80%)**
- **Reliability and Maintainability (10% - 40%)**

Design Anywhere, Manufacture Anywhere Collaboration

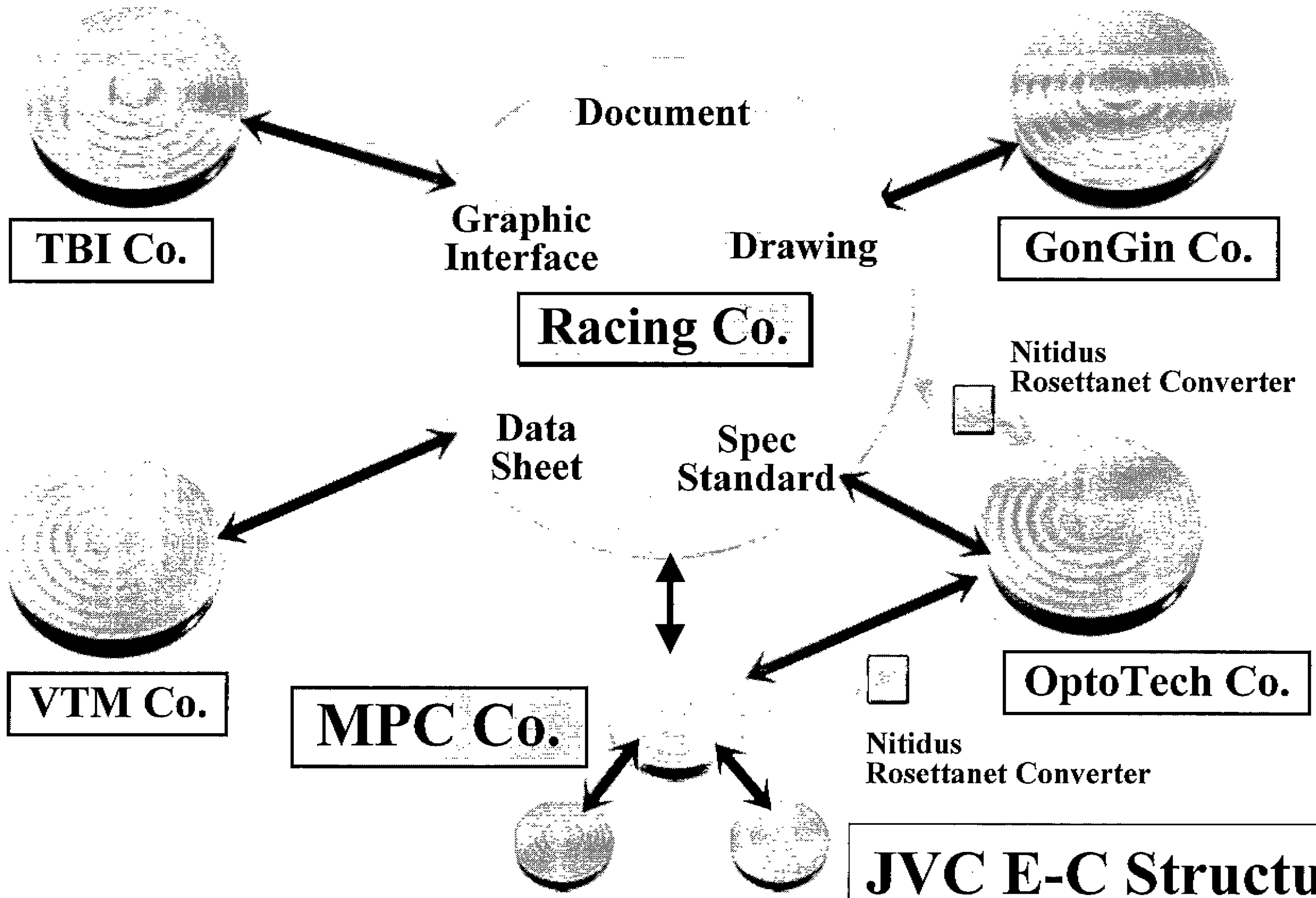
10. JVC e-Commerce at hand

Driving Trends：For Contracted Manufacturing to DAMA

- Rapid Product Introductions
- Increased Product Complexity
- Condensed Product Lifecycles
- Shorter Lead Times
- Tighter Cost Control
- Demands for Better Asset Utilization
- Requirement to Reduce Risk from Component Price Fluctuations and Component Shortages
- Rapidly Adjustment of Manufacturing Processes and Technologies
- Distributed and Varied Market Demand Requires Load Balancing

10. JVC e-Commerce at hand

JVC DAMA Collaborative Portal



JVC E-C Structure

10. JVC e-Commerce at hand

Major Company Entered into e-Commerce

ADC Telecom	Air France
Airbus	Australia Defense
AVL List GmbH	Babcock & Wilcox
BAE SYSTEMS	Bombardier
Boeing	Caterpillar Solar Turbines
Hutchinson Tech.	ITT Aerospace
KMTG	Litton/Ingalls Shipbuilding
Lockheed Martin	Lucent Technologies
Marconi Com	Moog
Sundstrand	Teldyne

10. JVC e-Commerce at hand

Extended Benefit: For JVC Partnership

- Respected Position in Aerospace industry
- Key Relationships with Suppliers and Contractor
- Deep understanding of Core Business Processes in Component Design and Manufacturing
- Aerospace Product Content That Can Be Leveraged in a Collaborative Portal Environment for Increased Competitiveness
- Building Momentum Within and Across Business units

附 件 二

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MPC PRODUCTS CORPORATION

QUALITY SYSTEM TRAINING

Sept. 19, 2000

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AGENDA

- MPC's Quality System
- D19000
- AS9100
- 5 S
- Lean Manufacturing Overview
- 6 Sigma Overview

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Quality at MPC

→ ISO9001 Registered ←

Qualified to MIL-Q-9858

☎MIL-I-45208	Insp. System
☎MIL-STD-45662A	Calibration Sys.
☎MIL-STD-105E	Sampling Proc.
☎MIL-STD-1520C	Corrective Action
☎MIL-PRF-38534	Hybrid Mfg.

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MPC's Documentation

➢ LIST OF OUR PROCEDURES

- ☎ ISO5903001 - QUALITY MANUAL (Level 1 Procedure)
- ☎ ISO5903010 - MANAGEMENT REVIEW PROCEDURE
- ☎ ISO5903020 - QUALITY SYSTEM
- ☎ ISO5903030 - PROCEDURE FOR CONTRACT REVIEW
  - 9995901031 - REQUEST FOR QUOTATIONS
  - 9995901035 - REPEAT ORDERS PROCEDURE
  - 9995901034 - NEW APPLICATION ORDERS
  - 9995901032 - SPARE PARTS ORDERS
  - 9995901033 - CONTRACT REVIEWS
  - 9995901030 - REVERSALS, PRICE CHANGE AND DELIVERY DATES
  - 9995901050 - SALES PROCEDURE FOR SPECIFICATION REVIEWS

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LIST OF OUR PROCEDURES (cont.)

☎ **ISO5903040 - DESIGN CONTROL PROCEDURE**

- ISO5903050 - DOCUMENT AND DATA CONTROL
- 9995901036 - SALES PROCESS OF PROTOTYPE MEETINGS
- 9995903203 - CHANGE REQUEST/ORDER PROCEDURE
- 9995903176 - INTENT CHANGE REQUEST PROCEDURE
- 9995903204 - ENGINEERING CONTROLLED DRAWINGS
- 9995901027 - DESIGN HIGHLIGHT REVIEW
- 9995901028 - PRELIMINARY DESIGN REVIEW
- 9995901029 - CRITICAL DESIGN REVIEW
- 9995901025 - CRITIQUE MEETING PROCEDURE
- 9995901026 - DESIGN MEETING PROCEDURE
- 9995901023 - KICK-OFF MEETING PROCEDURE
- 9995901024 - STRATEGY MEETING PROCEDURE

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LIST OF OUR PROCEDURES (cont.)

☎ **ISO5903050 - DOCUMENT AND DATA CONTROL**

- 9995903204 - ENGINEERING CONTROLLED DRAWING
- 9995900001 - PART NUMBER PROCEDURE
- 9995900010 - PART MASTER FILE PROCESS
- 9995903347 - DEVIATION PROCEDURE
- 9995903150 - OPERATION SHEET PROCEDURE (CREATING OPSHEETS)
- 9995903203 - CHANGE ORDER SYSTEM
- 9995903176 - INTENT CHANGE REQUEST
- 9995903341 - EXTERNAL DOCUMENTS
- 9995903343 - TECHNICAL DATA CONTROL
- 9995903345 - FORM NUMBER PROCEDURE
- 9995903348 - FABRICATION SHOP DOCUMENTS PROCEDURE
- 9995903177 - FLOOR CONTROLLED DOCUMENTS
- 9995903141 - STOP/START WORK ORDERS PROCEDURE
- 9995903342 - TOOL DESIGN, MANUFACTURING AND MANAGEMENT

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LIST OF OUR PROCEDURES (cont.)

☎ ISO5903060 - PURCHASING PROCEDURE

- 9995903359 - PRODUCTION MATERIAL PURCHASING
- 9995903360 - SECONDARY PROCESS PURCHASING
- 9995903361 - NON-PRODUCTION PURCHASING
- 9995903362 - MATERIAL REQUISITIONS
- 9995903363 - DEBIT MEMO PROCESSING
- 9995903364 - SUPPLIER APPROVAL AND DISQUALIFICATION
- 9995903365 - SUPPLIER QUALITY SURVEY
- ISO5903101 - RECEIVING INSPECTION
- 9995903366 - SUPPLIER RATING SYSTEM (OVERALL RATING)
- 9995903008 - SUPPLIER CERTIFICATION
- 9995903373 - FAB SHOP INSPECTION/QUALIFICATION PROCEDURE
- 9995903369 - SUPPLIER CORRECTIVE ACTION SYSTEM

LIST OF OUR PROCEDURES (cont.)

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- ISO5903070 - CONTROL OF CUSTOMER SUPPLIED PRODUCT
  - ISO5903101 - RECEIVING INSPECTION
  - ISO5903110 - CONTROL OF TEST EQUIPMENT
  - ISO5903130 - CONTROL OF NONCONFORMING MATERIAL
  - 9995903342 - TOOL DESIGN, FABRICATION AND MANAGEMENT
  - ISO5903030 - CONTRACT REVIEW
  - 9995903186B - CONTROL OF GOVERNMENT FURNISHED PROPERTY

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LIST OF OUR PROCEDURES (cont.)

ISO5903080 - PRODUCT IDENTIFICATION AND TRACEABILITY

- 9995900001 - PART NUMBER PROCEDURE
- 9995900010 - PART MASTER FILE PROCESS AND MAINTENANCE PROCEDURE
- 9995412001 - SERIAL NUMBER ASSIGNMENT PROCEDURE
- ISO5903160 - QUALITY RECORDS PROCEDURE
- 9995901035 - ORDER ENTRY PROCEDURE
- 9995901037 - COE PROCEDURE
- 9995903175 - SERIAL NUMBER PREFIX PROCEDURE
- 9995903188 - TRACEABILITY SPACE FLIGHT DEVICES PROCEDURE
- 9995903148 - SOLDERABILITY CERTIFICATION PROGRAM
- 9995903189 - LASER WELDING CERTIFICATION
- 9995903368 - PREVENTATIVE MAINTENANCE FOR MACHINE SHOP EQUIPMENT

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LIST OF OUR PROCEDURES (cont.)

ISO5903090 - MPC PROCESS CONTROL

- 9995903169 - COMPLETION OF OPERATIONS ROUTING SHEETS
- 9995903150 - CREATING OPERATIONS ROUTING SHEETS
- ISO5903160 - QUALITY RECORDS
- 9995901037 - COE PROCEDURE
- 9995903342 - TOOL DESIGN FABRICATION AND MANAGEMENT PROCEDURE
- ISO5903050 - DOCUMENT AND DATA CONTROL
- 9995903127 - SPECIAL PROCESS CONTROL
- 9995903183 - MATERIAL AUDIT PROCEDURE
- 9995902343 - RECEIVING PROCEDURE
- 9995903373 - FAB SHOP PART INSPECTION/QUALIFICATION PROCEDURE
- 9995903115 - HANDLING FINISHED GOODS WHICH REQUIRE CUST./GOVT. SOURCE INSPECTION
- 9995903802 - HANDLING FINISHED UNITS WHICH REQUIRE BOEING SOURCE DELEGATION ACCEPTANCE

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LIST OF OUR PROCEDURES (cont.)

- **ISO5903101 - RECEIVING INSPECTION PROCEDURE**
- **ISO5903102 - INPROCESS INSPECTION PROCEDURE**
- **ISO5903103 - FINAL INSPECTION PROCEDURE**
  - 9995903103 - MATERIAL INSPECTION REPORT
- **ISO5903130 - CONTROL OF NONCONFORMING MATERIAL**
  - 9995903167 - ESD PROCEDURE
  - 9995903182 - QCDR INSPECTION RECORD SYSTEM
  - 9995903129 - SAMPLING PLAN
  - 9995903180 - FIRST ARTICLE INSPECTION PROCEDURE
  - 9995903152 - STOCK SWEEP PROCEDURE
  - 9995903150 - CREATION OF OPERATIONS SHEETS (REWORK)

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LIST OF OUR PROCEDURES (cont.)

- **ISO5903110 - CONTROL OF INSPECTION, MEASUREMENT AND TEST EQUIPMENT**
  - 9995903012 - MECHANICAL GAGE CONTROL, COMPUTERIZED RECORDS
  - 9995903134 - MECHANICAL INSPECTION EQUIPMENT CALIBRATION
  - 9995903371 - ELECTRICAL CALIBRATION PROCEDURE

- **ISO5903120 - INSPECTION AND TEST STATUS**
  - ISO5903101 - RECEIVING INSPECTION
  - ISO5903102 - INPROCESS INSPECTION
  - ISO5903103 - FINAL INSPECTION
  - ISO5903130 - CONTROL OF NON-CONFORMING MATERIAL
  - ISO5903190 - SERVICING PROCEDURE
  - 9995903112 - INSPECTION STAMPS

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LIST OF OUR PROCEDURES (cont.)

☎ **ISO5903130 - CONTROL OF NON-CONFORMING MATERIAL**

- 9995903150 - CREATION OF OPERATIONS ROUTING SHEETS
- 9995903169 - USE OF OPERATIONS ROUTING SHEETS
- 9995903103 - USE OF MATERIAL INSPECTION REPORT
- ISO5903160 - QUALITY RECORDS (STORAGE AND RETENTION)
- ISO5903140 - CORRECTIVE AND PREVENTIVE ACTION
- 9995903344 - SCRAP PROCEDURE
- 9995903179 - REPORT TO MANAGEMENT
- 9995903378 - CUSTOMER/GOVERNMENT NOTIFICATION OF DISCREPANT MATL.

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LIST OF OUR PROCEDURES (cont.)

- **ISO5903140 - CORRECTIVE AND PREVENTIVE ACTION**
  - 9995903171 - FAILURE ANALYSIS PROCEDURE
  - ISO5903130 - CONTROL OF NON-CONFORMING MATERIAL
  - 9995903103 - USE OF MATERIAL INSPECTION REPORT
  - 9995903203 - CHANGE ORDER PROCEDURE
  - ISO5903170 - INTERNAL AUDITING
  - ISO5903190 - CUSTOMER SERVICING (COMPLAINTS)
  - 9995903370 - INTERNAL CORRECTIVE/PREVENTATIVE ACTION
  - 9995903369 - SUPPLIER CORRECTIVE ACTION PROCEDURE
  - 9995903178A - QUALITY BULLETIN
- **ISO5903151 - HANDLING**
- **ISO5903152 - STORAGE AND PRESERVATION**

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LIST OF OUR PROCEDURES (cont.)

☎ **ISO5903153 - PACKAGING AND DELIVERY**

- 9995903167 - ESD HANDLING PROCEDURE
- 9995902337 - PACKAGING METHODS AND PROCEDURES
- 9995903205 - QUALITY CLEANLINESS AND ATMOSPHERE CONTROL PROCEDURE
- 9995902338 - STORAGE AND PRESERVATION
- 9995903115 - FINISHED GOODS PROCEDURE
- 9995902339 - DELIVERY OF PRODUCT
- 9995902337 - PACKAGING METHODS AND PROCEDURES

☎ **ISO5903160 - QUALITY RECORDS**

- ISO5903050 - DOCUMENT AND DATA CONTROL
- 9995903146 - LIMITED RIGHTS PROCEDURE
- QRML - QUALITY RECORD MASTER LIST

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LIST OF OUR PROCEDURES (cont.)

- **ISO5903170 - INTERNAL QUALITY AUDITS**
  - ISO5903140 - CORRECTIVE AND PREVENTIVE ACTION
  - 9995903370 - INTERNAL CORRECTIVE/PREVENTATIVE ACTION
- **ISO5903180 - MPC TRAINING**
  - 9995903381 - ADVANCED QUALITY SYSTEM TRAINING
- **ISO5903190 - PROCEDURE FOR SERVICING**
  - 9995901038 - RETURNED GOODS PROCEDURE
  - 9995901039 - SALES REPAIR PROCESS

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LIST OF OUR PROCEDURES (cont.)

☎ ISO5903200 - STATISTICAL TECHNIQUES

- 9995903129 - STATISTICAL SAMPLING PLAN
- 9995903380 - ADVANCED QUALITY SYSTEM
- 9995903381 - ADVANCED QUALITY SYSTEM TRAINING

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Certified Soldering

Instructor Certified to:

- NHB5300.4(3A-2)
  - ☎ 14 Employees Certified
- ANSI J-STD-001B
  - ☎ 96 Employees Certified

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Space Q.A. Experience

- Space Shuttle 6 Applications
- Space Station 5 Applications
- Numerous Satellite Applications
  - Including Solar Array Drive System
- Configuration Management System to MIL-STD-483 & MIL-STD-973

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TRACEABILITY

- Experience with many Space Applications (Previously Discussed)

- MPC Has an Internal Procedure (9995903188A) For Traceability.
  - ☎ <u>Compliant</u> with <u>Boeing</u> <u>ELV-JC-002D</u>

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Customer Approvals

- 1990 - 1999 Trained over 180 Employees in SPC
  - SPC System approved by:
    - Boeing
    - Lockheed Martin
    - Hughes
- Boeing D19000 rev. A
- Lockheed Martin STAR Supplier Award (1997)

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Boeing D19000 rev. A

- Quality System Requirements - Accepted by Aerospace Industry
  - Consists of Basic Quality System (BQS)
    - ISO9001 Plus Many additional requirements
  - Advanced Quality System (AQS)
    - Statistical Techniques

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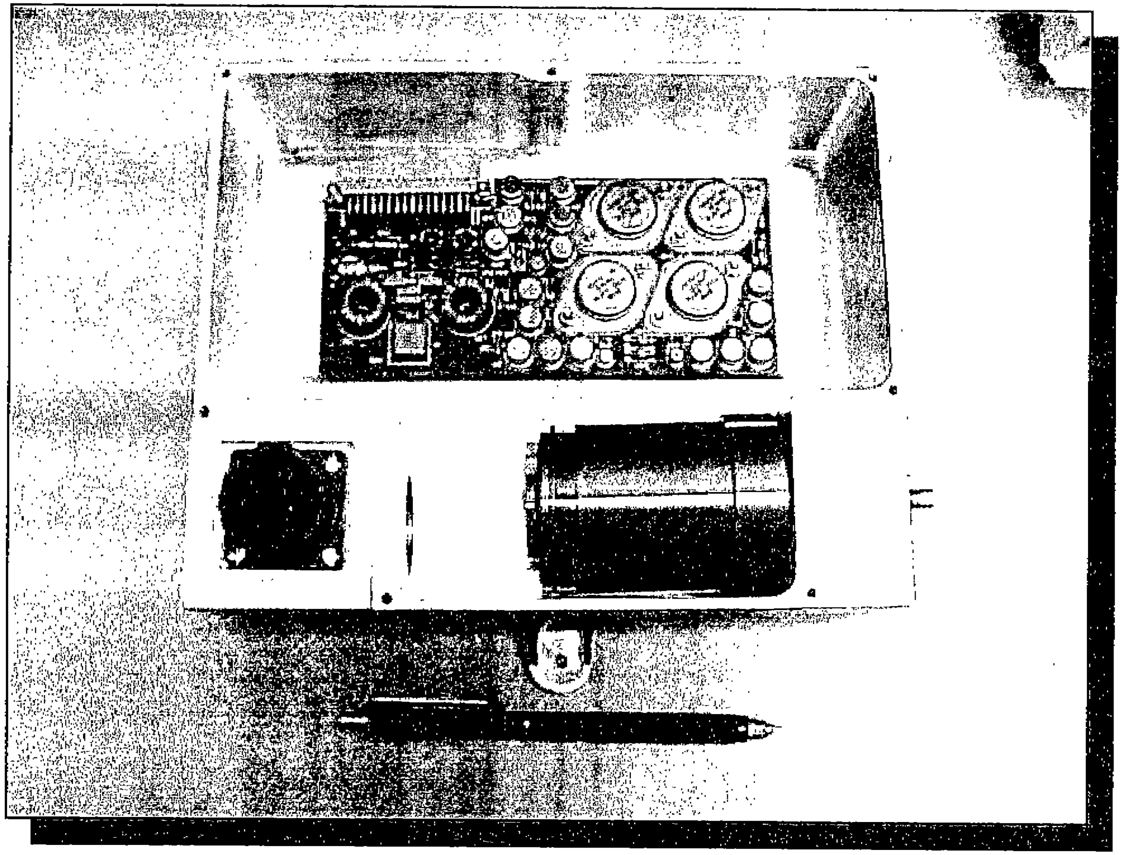
AS91000

- Aerospace Quality System Standard
  - Incorporates ISO9001 plus additional requirements
  - Will be the Quality System required by Boeing for it's suppliers
  - The US government is also considering using it.
  - Other major US Aerospace Primes will follow Boeing's Lead.

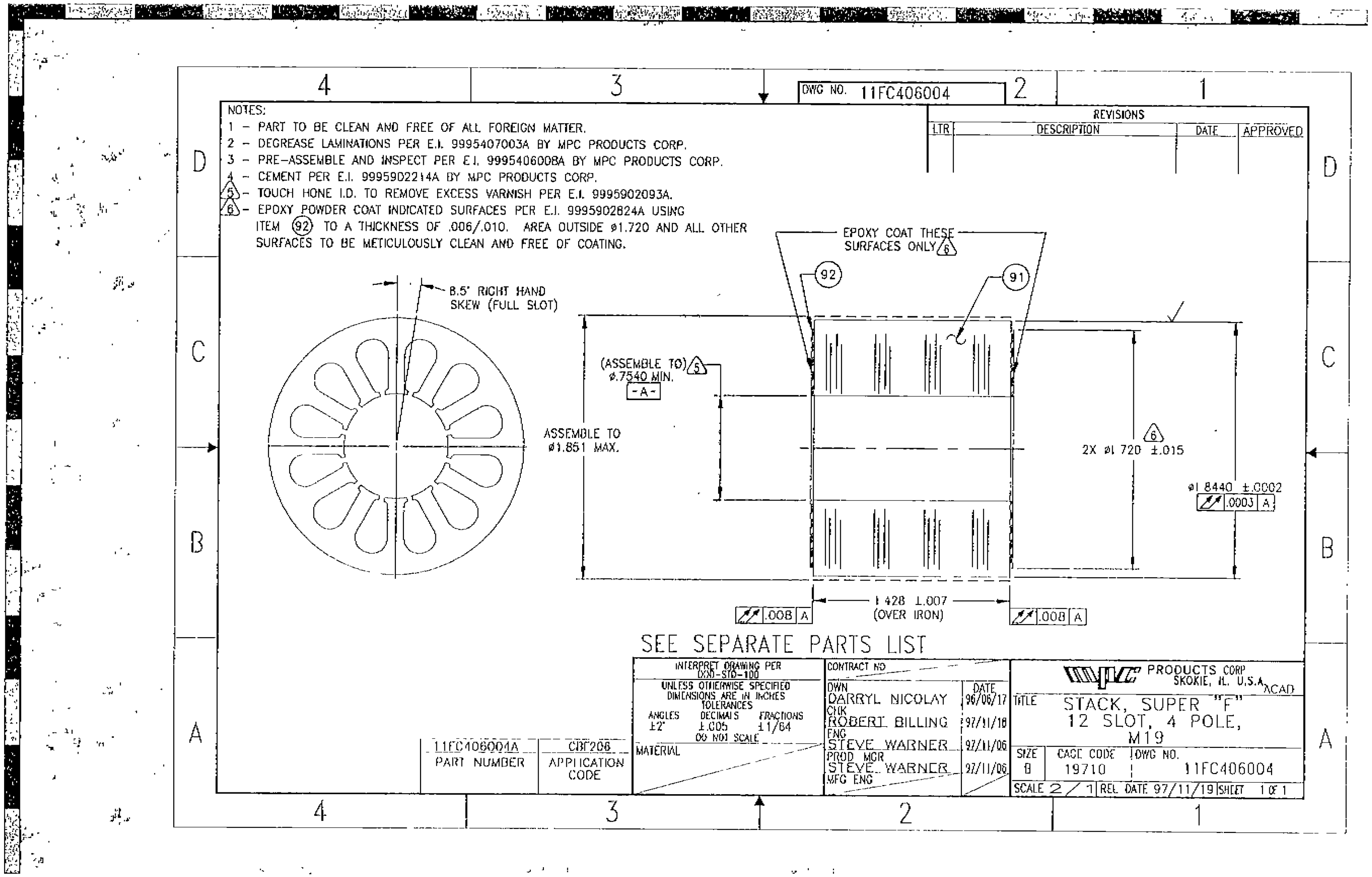
附 件 三

MPC PRODUCTS CORP.

Super "F" Motor/Controller



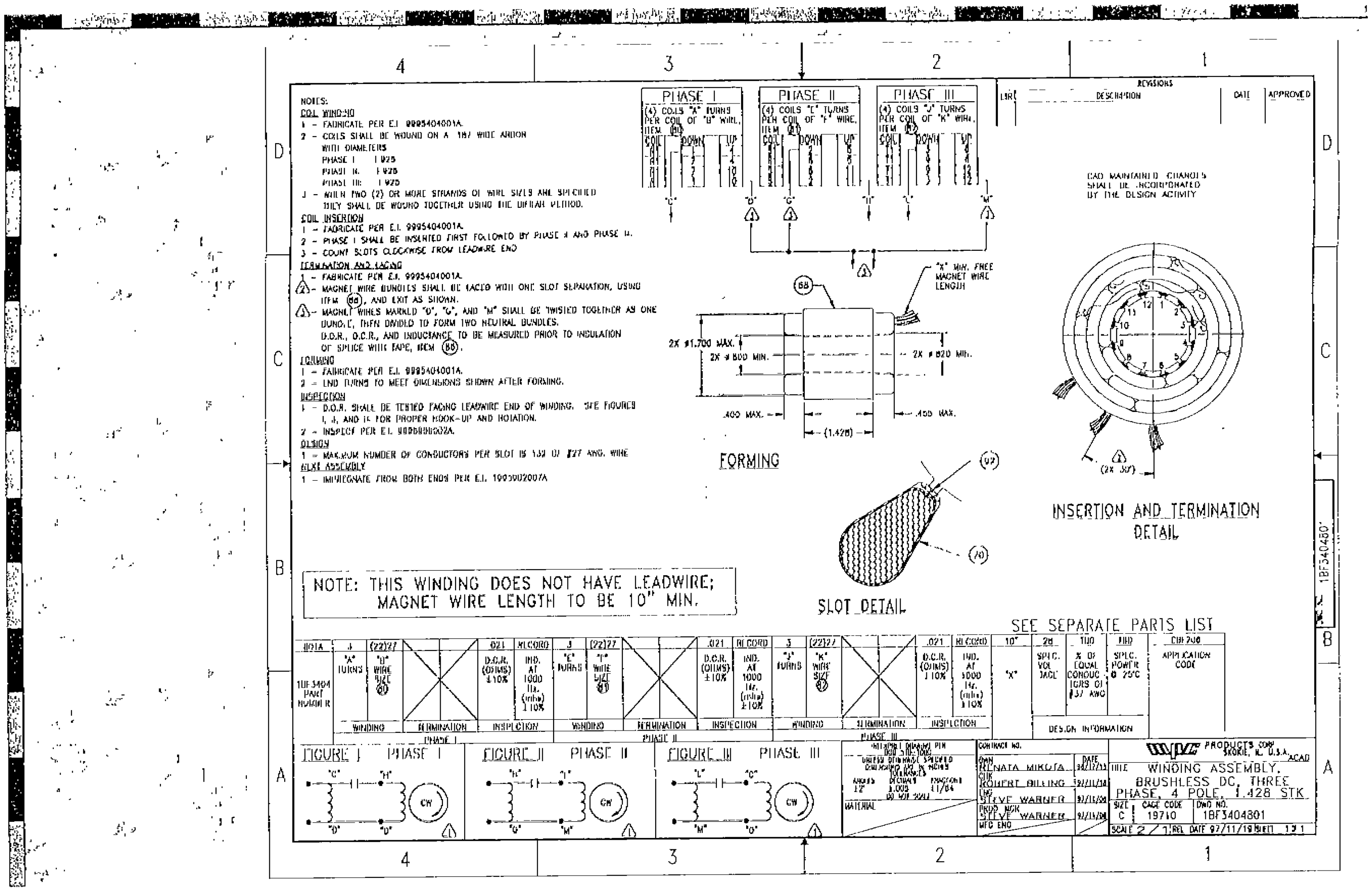
Motor Stack Assembly



Motor Stack Assembly

- Degreasing Laminations E.I. 9995407003 (Note 2)
- Pre-Assembly and Inspect E.I. 9995406008 (Note3)
- Cementing E.I. 9995902214 (Note 4)
- Touch Hone I.D. 9995902093 (Note 5)
- Epoxy Powder Coat E.I. 9995902824 (Note 6)

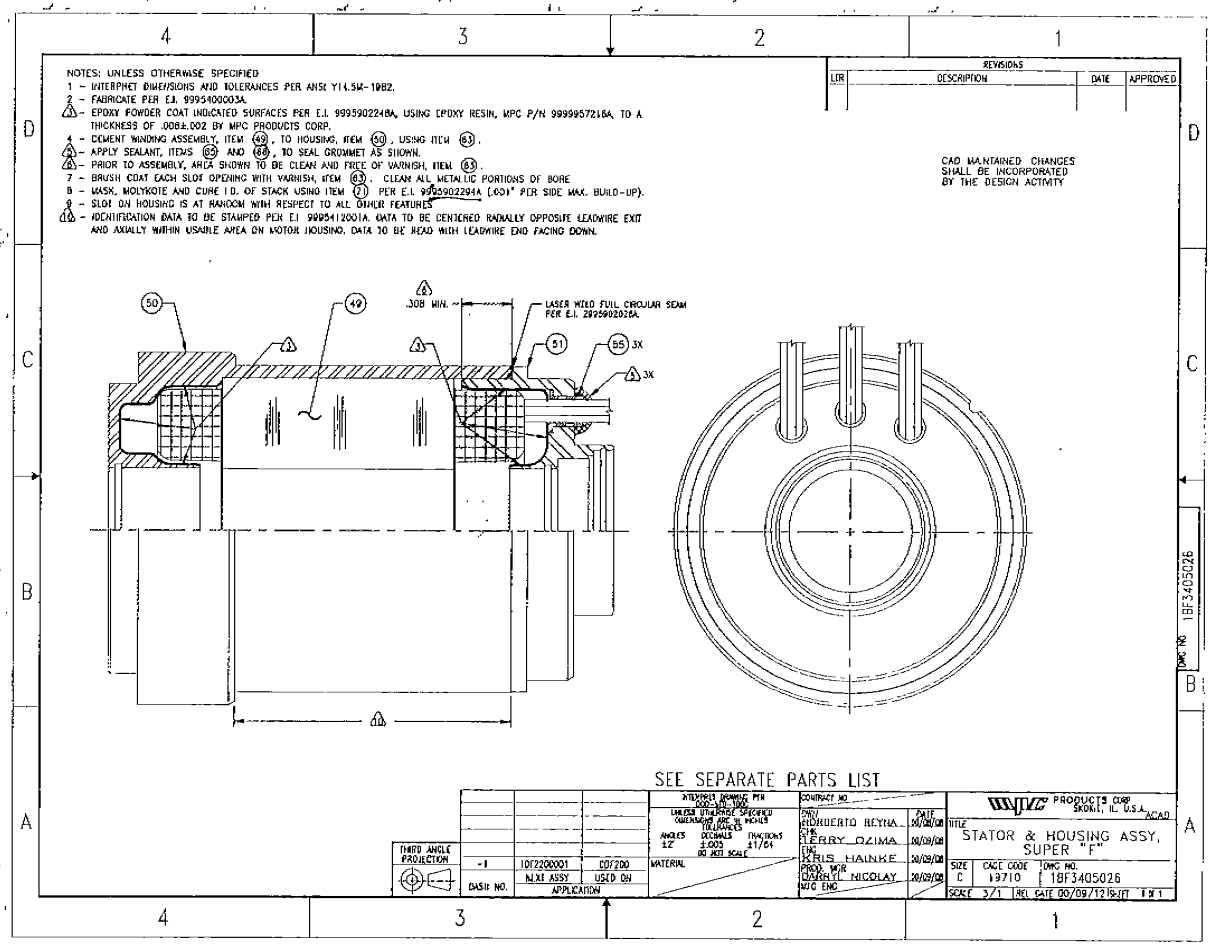
Motor Winding Assembly



Motor Winding Assembly

- Fabricate per E.I. 995404001
  - Coil Winding
  - Coil insertion
  - Termination and Lacing
  - Forming
- Inspection E.I. 9995906002

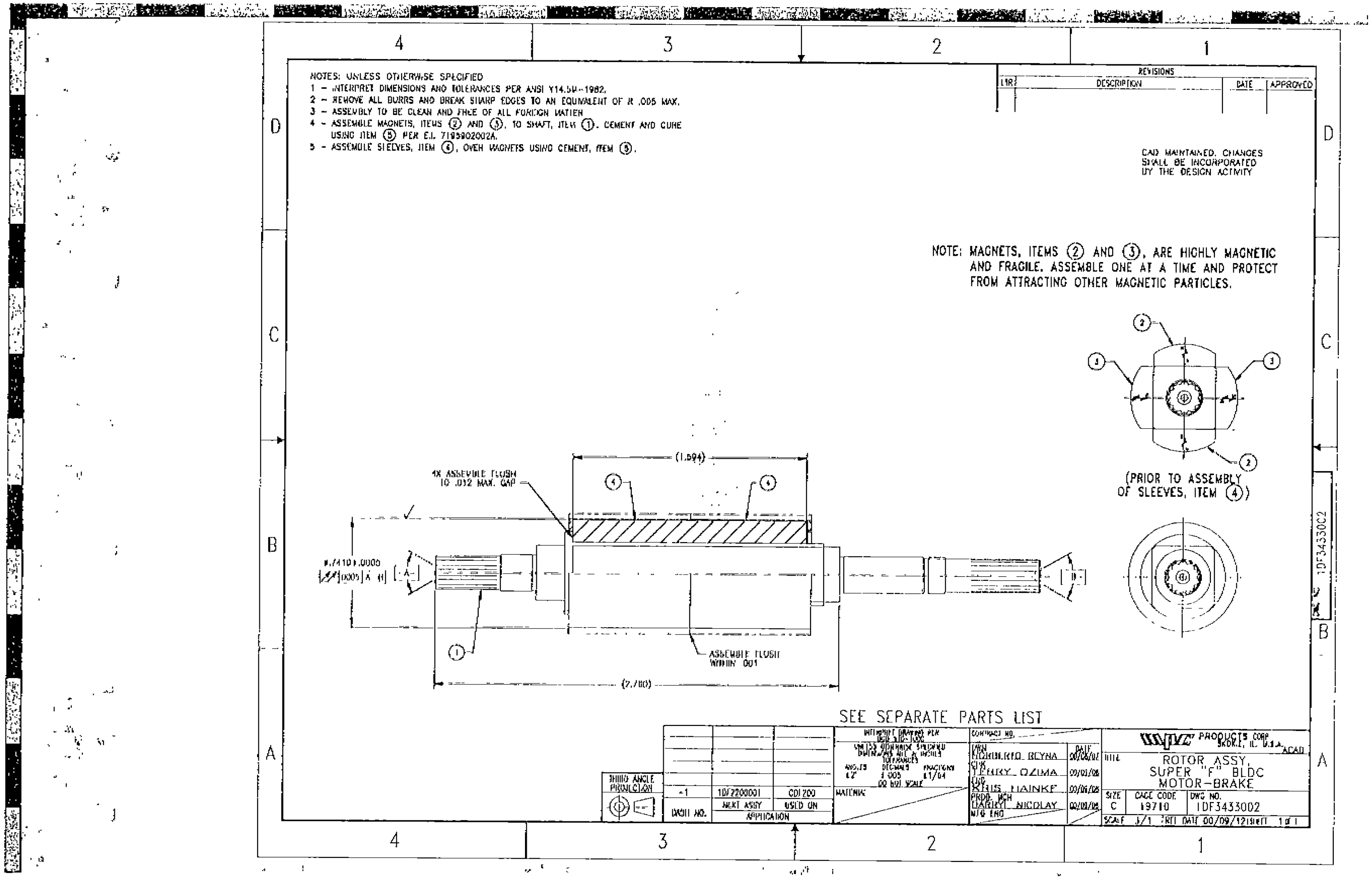
Motor Stator Housing



Motor Stator Housing

- Fabricate per E.I. 9995400003A
- Powder Coating (Note 3)
- Molycoat Motor Bore (Note 8) [illegible] 999-5P02-[illegible]
- Identification Data (Note 10)

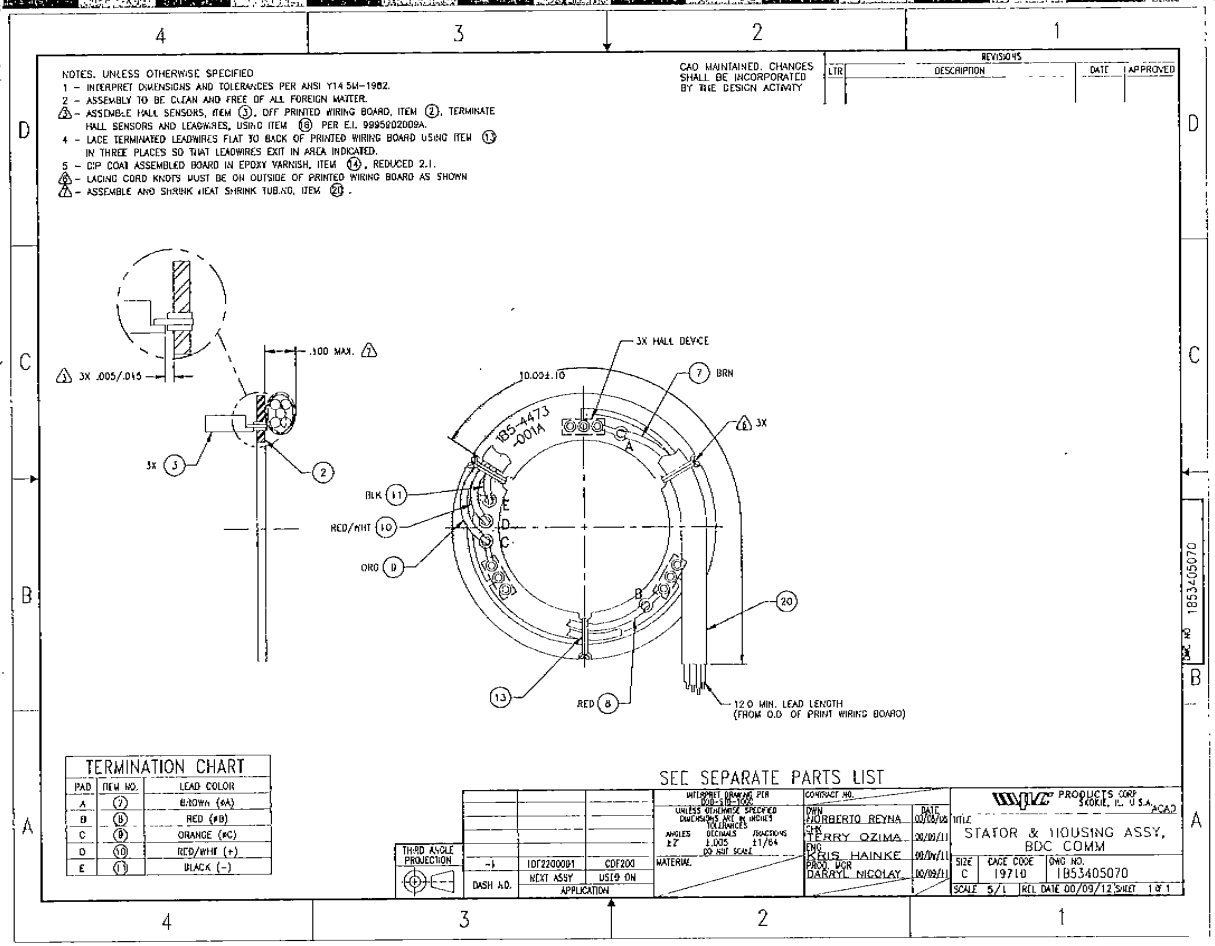
Motor Rotor Assembly



Motor Rotor Assembly

- Assemble Magnets
- Assemble sleeves
- Grind O.D.

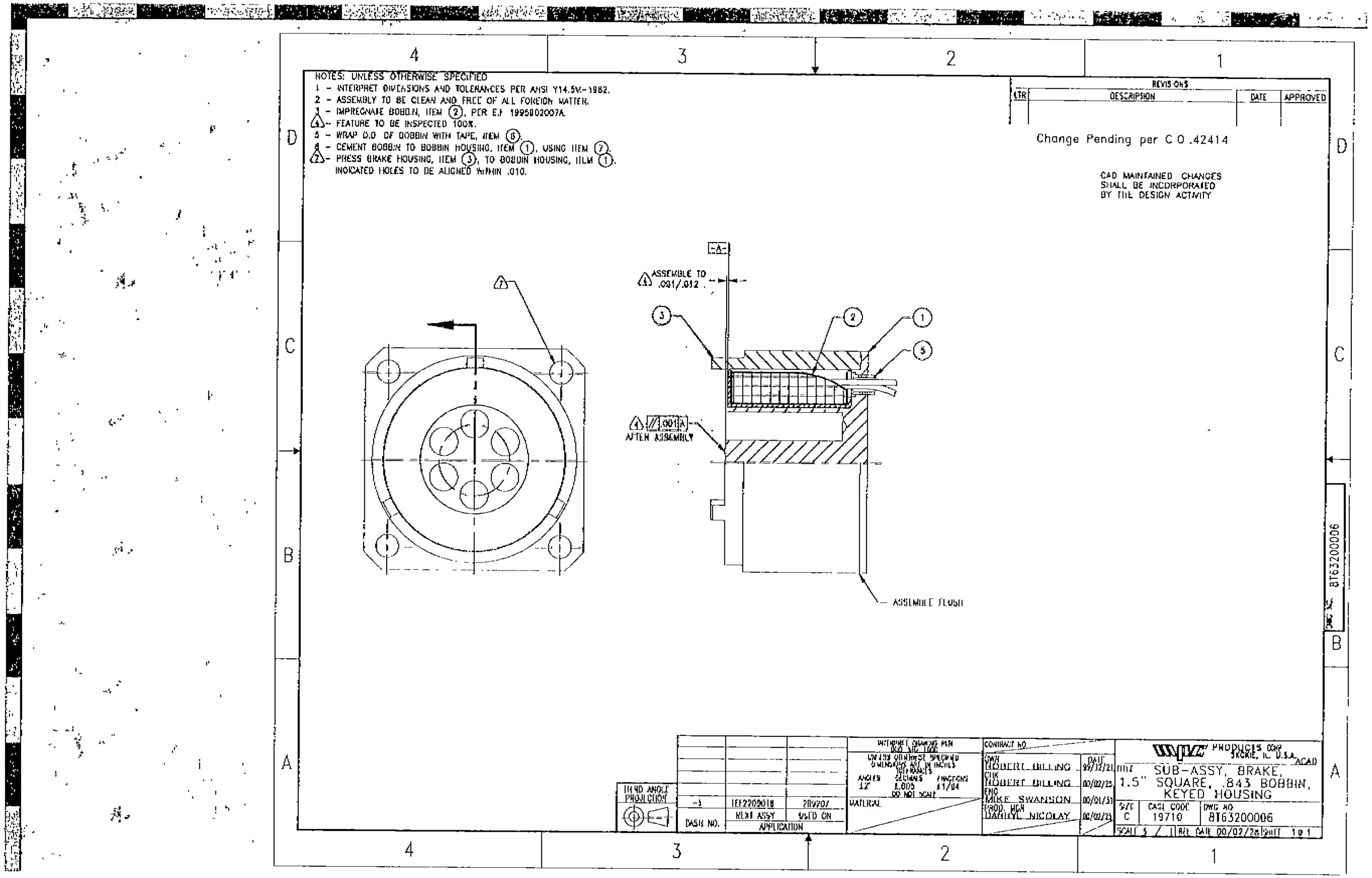
Stator Housing Assembly BDC Comm



Stator Housing Assembly BDC Comm

- Hall Sensors
  - Assemble
  - Terminate E.I. 9995902009 (Note 3)
- Dip Coating (Note 5)
- Assemble Tubing (Note 7)

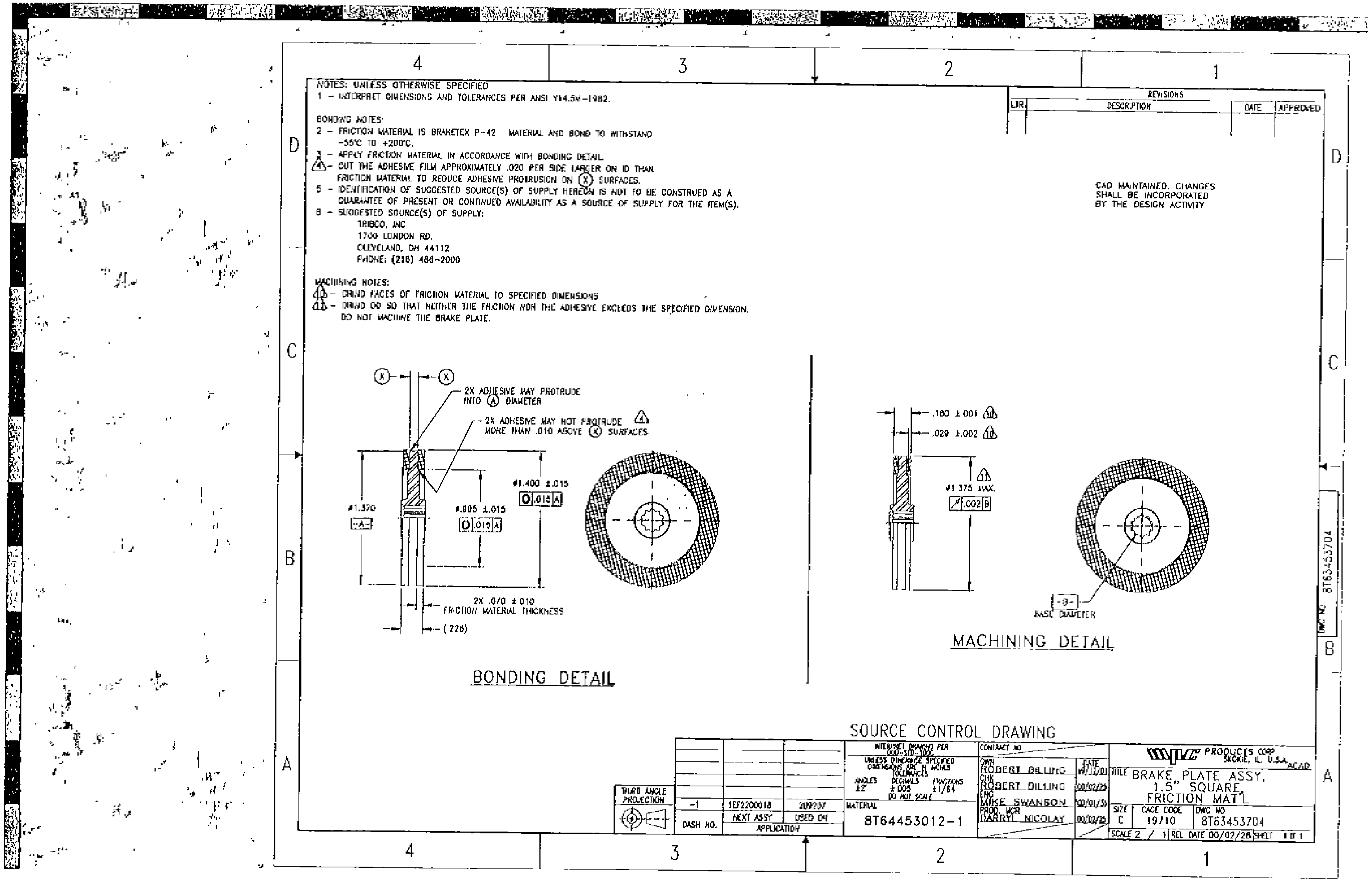
Sub-Assembly Brake



Sub-Assembly Brake

- Impregnate Bobbin E.I. 1995902007 (Note 3)
- Wrap O.D. (Note 5)
- Cement Bobbin to Housing (Note 6)
- Assemble to housing (Note 7)

Brake Plate Assembly



Brake Plate Assembly

- Assembly is fabricated by an outside source for bonding of Friction material - MPC will supply this assembly

Motor Final Assembly

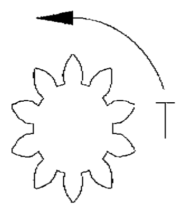
- Assemble and Test E.I. 1995902027
  - Fit of bearings (Note 4)
  - Axial Play of Shaft (Note 6)
  - Cementing of BDC Commutator (Note 9)
  - Align and test Commutator (Note 10)
  - Brake Assembly
  - Testing

附 件 四

THE DESIGN AND CONSTRUCTION OF BLDC MOTORS

TABLE OF CONTENTS

Torsional Stress on Motor Shaft



The torsional stress on the motor shaft may be calculated using the following expression:

$$\tau = \frac{T \times d}{32 \times J}$$

Where: τ = shear stress (psi)
T = applied torque (in-oz)
d = minor diameter of spline (in.)
J = polar moment of inertia (in^4)

For this example : T= 200 in-oz
d = .191 in.

$$J = \frac{\pi \times d^4}{32} = 1.31 \times 10^{-4} in^4$$

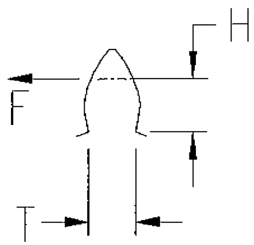
And :

$$\tau = \frac{200 \times .191}{32 \times .000131} = 9{,}913 \quad psi$$

In this example the shaft material is 17-4 PH stainless steel and the allowable shear stress for this material is 72,700 psi. The factor of safety (F_s) is given by :

$$F_s = \frac{allowable \quad stress}{actual \quad stress} = \frac{72{,}700}{9{,}913} = 7.3$$

Bending Stress on Spline Tooth



The bending stress on a spline tooth may be calculated using the following expression:

$$\sigma = \frac{6 \times F \times H}{T^2}$$

For this example: σ = bending stress on spline tooth (psi)
F = tangential force due to gear mesh (lbs.)
H = distance from minor dia. to pitch dia. (in.)
T = minimum tooth thickness (in.)

So $F = \frac{Torque}{Radius} = \frac{200 \;\; in-oz}{.098 \;\; in} = 2{,}041 \;\; oz$; $\frac{2{,}041 \;\; oz}{16} = 127.6 \;\; lbs$

And in this example: H = .006 in. and T = .041 in.

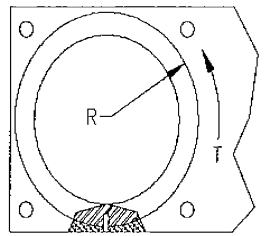
Substituting these values into the bending stress equation yields :

$$\sigma = \frac{6 \times 127.6 \times .006}{.041^2} = 2{,}733 \quad psi$$

The shaft material is 17-4 PH stainless steel and the allowable shear stress for this material is 72,700 psi. The factor of safety is given by :

$$F_s = \frac{allowable \;\; stress}{actual \;\; stress} = \frac{72{,}700}{2{,}733} = 26.6$$

Pin Shear on Roll Pin



The shearing force is given by : $F = \frac{T}{16 \times R}$

Where : F is the shearing force (lbs.)
T is the motor torque (in-oz)
R is the outside radius of the motor housing (in.)

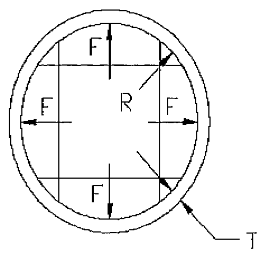
For this example : T= 200 in-oz
R = 1.081 in.

So $F = \frac{200 \ \ in-oz}{16 \times 1.081 \ \ in} = 11.6 \ \ lbs$

Military Standard MS51923 defines the minimum double shear force allowable for this type of roll pin. For the .062 in. diameter pins used here, the minimum double shear force is 250 lbs. In this application there is one pin in single shear so the allowable single shear force is half of the double shear force, or 125 lbs. The factor of safety is given by :

$$F_s = \frac{allowable \ \ force}{actual \ \ force} = \frac{125}{11.6} = 10.8$$

Hoop Stress on Magnet Cups



In case of adhesive failure, two 303 stainless steel (non-magnetic) cups are provided for secondary retention of the rotor magnets. The centrifugal force of unbonded magnets would induce hoop stresses in the magnet cups.

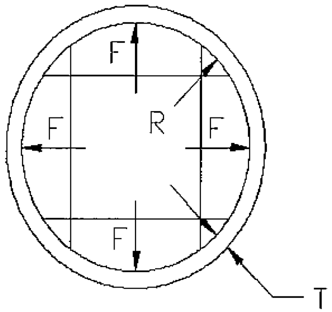
The centrifugal force of a magnet rotating around the axis of the rotor is given by : $F = .000341 \times W \times D \times N$

Where : F = centrifugal force (lbs.)
W = weight of magnets (lbs.)
D = distance from axis of rotation to the center of gravity of the magnet (in.)
N = revolutions per minute (RPM)

In this example : W = .026 lbs.
D =.280 in.
N = 12,000 RPM

And : $F = .000341 \times .026 \times .280 \times 12{,}000 = 357.5 \quad lbs$

Hoop Stress (Cont'd)



The hoop stress in the magnet cups is given by :

$$\sigma = \frac{P \times R}{T}$$

Where : σ = hoop stress (psi)
P = pressure (psi)
R = inside radius of cup (in.)
T = wall thickness of cup (in.)

The pressure (P) is calculated as follows : $P = \frac{F}{A}$

Where : F = centrifugal force = 357.5 lbs
A = surface area of magnets in contact with magnet cup=.708 in²

And : $P = \frac{357.5}{.708} = 505 \quad psi$

For this unit : R = .364 (in.)
T = .0075 (in.)

And we know : P = 505 psi

Substitute these values into the equation to determine the hoop stress in the magnet cups.

$$\sigma = \frac{P \times R}{T} = \frac{505 \times .364}{.0075} = 24{,}509\,psi$$

The tensile strength of 303 stainless steel is 90,000 psi so the factor of safety (F_s) is :

$$F_s = \frac{90{,}000}{24{,}509} = 3.7$$

Bearing Life

We use deep groove (Conrad Type) radial ball bearings in most all motor designs.

Your bearing has an ID of .25" and an OD of .75". The quarter inch ID is very convenient. The .75 OD is slightly larger than the rotor diameter which makes the unit easy to assemble (and disassemble). This rotor to bearing OD match is very common in small motors, but not in larger motors because it is impractical for many reasons.

The bearing has a metal "ribbon" ball retainer and therefore has a "dn rating" of 80,000. (dn) is the product of the bore dimension in mm x the speed.

Therefore the speed rating of this bearing is: 80,000/((.25") x 25.4) = 12600

The life estimate relies on the use of L10 which is the life of which 90% of the bearings are expected to survive. L10 can be calculated by:

L10 = (rated load/actual load)^3 x E6 [revolutions]

Your bearing has a rated load of 160 lbs, and a Nil actual load because it is a spline drive. If we assume a 2 pound load to account for preload and make the equation work we get (for 12,000 RPM):

L10 = (160/2)^3 x E6 = 5 E11 revolutions = 43 E6 Minutes = 700,000 Hrs.

Which is very appropriate for an intermittent duty actuator.

Bearing Fits

Manufacturers (eg NHBB) recommend the fit of the bearings to the shaft and to the housing to be .0000/.0002 Inches loose at both interfaces.

MPC follows this practice. The bearings are slightly loaded in the axial direction using a wave spring. This accommodates movement over temperature, and keeps the balls rolling (rather than skating). The slight axial load also helps to keep the raceways from spinning at the shaft and housing to bearing interfaces so that the rotation occurs along the ball path where it is intended.

Fit and Retention of Winding to Housing

This motor stack is machined to transition fit (.0000/.0005"loose) into its housing. During assembly the OD of the stack is brushed with a viscous epoxy varnish (same as that which we use to impregnate the winding, but not reduced [thinned].

This standard practice is used by MPC on all small motors and we have established very high reliability with it.

At full torque the force at this interface would be just 13 Lbs acting on over 9 square inches of bonded interface. This equates to (13/9) = 1.44 PSI of lap shear, and any epoxy has a lap shear rating in the thousands of PSI although the electrical types are not usually tested that way.

Kv and its Derivation

The electromotive force (EMF) can be evaluated for the permanent magnet machine. This is also called the voltage constant or Kv.

Sometimes it is referred to as the generator constant or back EMF. It has units of volts per unit speed such as: Volts/Radian/Second, Volts/RPM, or Volts/KRPM.

It can be measured by mechanically driving the machine using another machine to do so and reading the output voltage at the terminals of the driven machine. This would be the generator mode. It can also be measured and calculated by running the machine under its own power. Assuming the mechanical losses (viscous or speed losses) are negligible, and they usually are, the machine can be run under its own power and the speed measured with a non contact device like a stroboscope.

The voltage applied divided by the measured speed will then also be the Kv:

Kv = (voltage*/Speed)

* voltage can either be applied (motor) or produced (generator) depending on the test method.

Kt and its Derivation

Kt is the motor torque constant. Its units are Torque per amp. Common units are: Nm/Amp or In-Oz/Amp. It is fortunate that Kt is easily derived from Kv. In fact, in SI units the two numbers are identical (one and the same):

Kv (V/Radian/Sec) = Kt (Nm/Amp)

The fact that they are the same is readily apparent by looking at the theoretical explanations:

V = NBLW Therefore **V/W = NBL= Kv**

T = NI x B(L) Therefore **T/I = NBL= Kt**

Where:
- V= Volts
- T= Torque
- N= # of turns
- B= Flux Density
- L = Magnetic Length
- I = Current
- W= Angular Velocity (Rad/Sec), which is dimensionless
- x = Vector Cross Product operation

Km: its Derivation & Significance

Km is called the motor constant, and it has several different formulations and applications. It is probably the most important figure of merit in permanent magnet motor design. Its units are: Torque / Square-root of Watt. Simply, it is directly the torque efficiency of the machine at stall. However, it also dominates the determination of motor efficiency (and motor capacity) at any speed. Some of the underlying equations are:

Km = T/ (Watt^0.5) Where T= Torque & W = Power in Watts

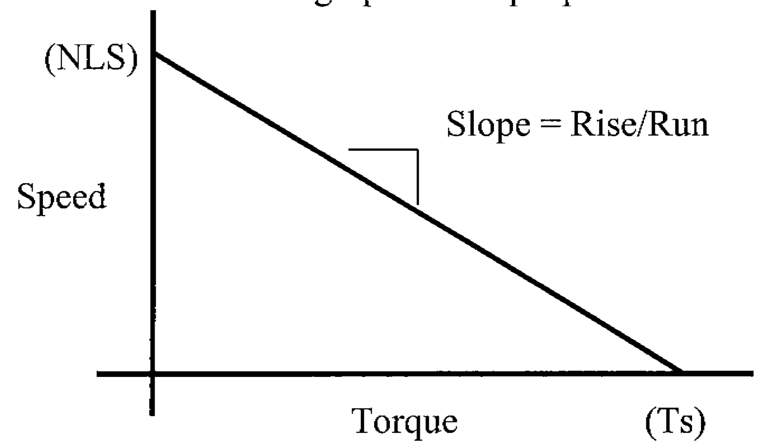
and we know that P = (I^2) x R so the Km expression can also be written:

Km = T / (((I^2) x R)^0.5) = (T/I) x (1/(R^0.5)) = Kt / (R^0.5)
[because we recognize that (T/I = Kt)]

This is a very important conclusion because we now know that the only way to increase Km is by increasing Kt or lowering R! In the following slide we will realize that practical limitations on power supply voltage and speed limitations of the shaft and its bearings will also bound Kv (and therefore Kt) within that practical range so that the secret of the high efficiency, or high capacity, machine is in fact to minimize the resistance (R) of that machine.

Km: its Derivation & Significance (cont'd)

Consider the following Speed-Torque plot:



No Load Speed (NLS) is calculated using the simple formula: **NLS = V/Kv**, where V is the the power supply voltage. The stall torque intercept (Ts) is calculated using:**Ts = (V/R) x Kt**. The slope (Rise/Run) is therefore:

$$\textbf{Slope} = \frac{-V/Kv}{(V/R)Kt} = -R/(Kv \times Kt) = -R/(Kt^2) = 1/(Km^2) \quad [\text{Because } Km = Kt/(R^{0.5})]$$

The most important conclusion is that:

higher Km = flatter slope = more torque at any speed = more power out at any speed

With practical and customer limits on power supply and bearing/shafting velocities NLS (and therefore Kv & Kt) will always fall within a certain expected range. The only parameter we have to develop more torque and power is the increase of Km by lowering the winding resistance.

Km: its Derivation & Significance (cont'd)

Kt for a given R can be increased to a degree by finding a stronger magnet (and this will increase Km), but the industry thinks Samarium Cobalt is at its strength limit, and there has been very little change with the Neodymium alloys over the past several years.

There are two ways to increase Km by changing the size of the machine and they are a longer motor stack or an increase in the machine diameter.

Longer Stack: if the end turns distance is negligible a doubling of the stack length will double the Kt and double the R. Solving for Km using Kt/(R^0.5) indicates that the Km will have improved by the square root of the stack length change (eg if the stack is doubled the Km will go up by 1.4x). However, the end turns are almost never negligible, and it usually turns out a bit better in practice.

Larger Diameter: Increasing the diameter of an already optimized machine will increase the Km by the diameter change squared. This is because there is a one times change due to the larger available area of copper and another one times change due to the increase of the rotor moment arm (Torque = force x distance). Therefore the doubling of the machine diameter would be a 4x improvement in Km.

Kv and its Calculation

The EMF or generated voltage of the PM machine can be directly calculated from the known dimensions, design details, and magnetic properties. From there Kv, Kt and Km can also be calculated. The specific equation for the generated voltage of this design (which is a variant of the simplified **V= BLV** from previous slides) is as follows:

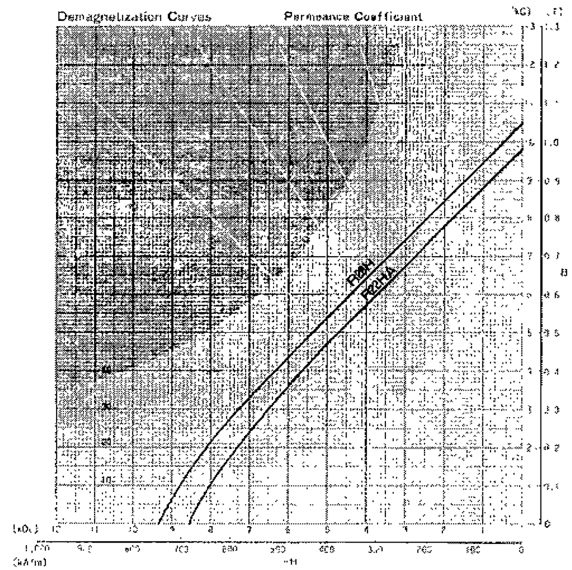
Voltage = (2) x N x #T x (2 x SIN 60) x Ls x V x B

Where:

(2)	= A multiplier because two coil ends reside in the same lamination slot
N	= The number of series poles in the machine which is 4 in this case.
#T	= The number of turns per coil which is 3 in this case.
2xSIN60	= A multiplier to represent the peak value of the Wye connection which is the peak cross over of the two isolated phases.
Ls	= The magnetic length (Stack and/or Rotor) in meters.
V	= The linear velocity of the rotor surface in meters/second. Which is 3.6 M/S at 3600 RPM.
B	= The flux density at the surface of the rotor in Tesla

Kv and its Calculation (Cont'd)

The most possible uncertainty lies in the determination of the value of flux density (B). We have found that a well proportioned lamination will allow a good wire fill (low R) while also acting as a very permeable magnetic circuit. Shown here is the B-H line for the 26 MGOe permanent magnet. The vertical intercept is is the residual induction or Br. If the lamination is good the magnet will operate very near to Br. If the lamination is not so good we have found the Km will be poor and the machine will be susceptible to torque saturation at higher levels of applied current. The Br of this material is nominally 1.1 Tesla.



Substituting in the previous equation all the necessary numbers:

Peak Voltage = (2) x (4) x (3) x (2SIN 60) x (.041) x (3.6) x (1.1) = 6.74 Vpk

And, 6.74 Vpk x (.707) = 4.77 VRMS (at 3600 RPM). Note that the manufacturing test limit for the design is 4.5/5.5 VRMS at 3600 RPM. This limit has been empirically adjusted in accordance with historical manufacturing data. It is usually considered very successful for magnetic calculations to fall within 10% of the actual measured characteristics.

R and its Calculation

The unit is a wye terminated, 4 pole, 3 turn, winding; and it is necessary to first calculate the resistance of one isolated leg. The path of each coil is down a slot around the end to the return slot (3 slots over) back up that slot and back over to the down slot (Ref: MPC drawing 1BF3404801A).

The stack length is 1.43" and the nominal path of the distance in the end turn is 1.10". Therefore the length of 1 coil is ((2 x 1.43) + (2 x 1.10)) = 5.06". We wind these coils on round arbors so the minimum arbor diameter would be 5.06/PI = 1.61 inches. But, we must allow some freedom in the coil ends to allow insertion of the interweaving phases so we add about 20% to the arbor diameter and use an actual arbor diameter of 1.925" as stated in Note 2 of the drawing. The resistance calculation proceeds as follows:

3 series turns x 4 series poles x 1.925" arbor diameter x PI = 73"

We also allow ten inches additional at each end (2x) for wire leading to the coils so the total length is 73 + 20 = 93 inches (7.8 ft). The resistance for a single strand is calculated by looking up the coefficient of resistance from a wire table for the specified AWG 27 size which is (51.4 Ohms/Kft) and multiplying by the required number of Kft:

7.8 ft x (51.4 Ohm/1000 ft) = .400 Ohms

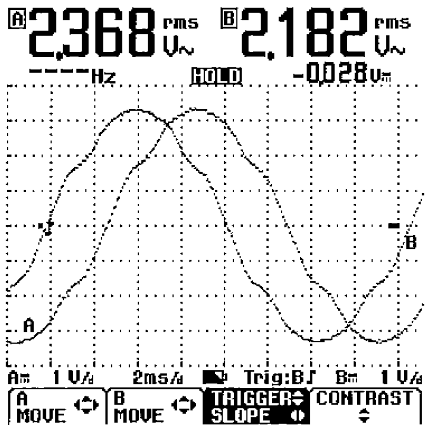
Because we have 22 strands in parallel we know that R of the parallel circuit will be equal to the single strand resistance divided by 22:

.400Ohms/ 22 parallel strands = .018 Ohms

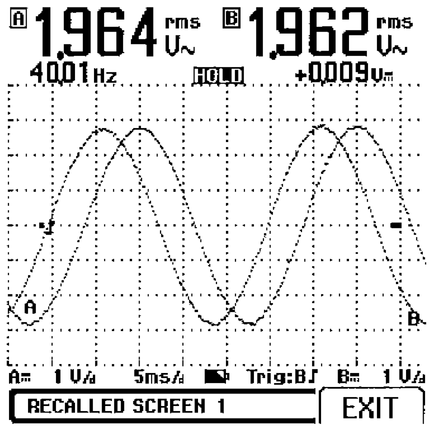
Additional allowance is made for wire stretch and the fact that the arbor diameter grows in diameter as it fills up so the actual drawing specification is thus .021 Ohms +/- 10%.

The Effects of Skew Angle

Skew angle is the progressive rotation of the laminations along the entire length of the stack in order to "Blend" the discrete effects of the individual teeth. Skew angle is measured from the end like a clock face. Skew angle is used to blend the Back EMF into a better sine wave (when desired), and reduce the unpowered detent torque.



Some Skew (CBF206)



More Skew (CMF210) Valve Drive

Materials Selection Rationale & Heritage

The following is a philosophy of all materials used in your motor:

Bearings- The raw materials of the bearings are 440 Stainless Steel. There is almost no cost premium for using stainless in this size, and it is corrosion resistant.

Bearing Lube - Is Braycote 601 which is an excellent perfluorether grease with high vacuum (High Alt.) service rating and also contains a corrosion inhibitor.

Steels - All steels are stainless. Magnetic steels are from the 400 series. Nonmagnetic are from the 300 series. All of them are passivated. Shafting is most often 17-4 or 13-8 because of the guaranteed strengthe properties.

Aluminum is 6061-T6 which is a recognize Aero. Alloy. It is always Chem film (Irridite) per Mil-Spec. or anodized where mechanical wear resistance is necessary.

Magnets are Samarium Cobalt 2-17 of the commonly know 26-28 MGOe. Samarium Cobalt has the highest thermal and corrosion resistance of all of the rare earth magnets.

Magnet Wire is Polyimide coated (Heavy) [HML] because of its mechanical toughness and Chemical resistance.

Materials Selection Rationale & Heritage (Cont'd)

Leadwire- Where used leadwire is Teflon or Tefzel insulated per MIL Spec. The Teflon wire is more flexible, and the Tefzel wire has a greater resistance to insulation damage.

Winding Varnish- Is MIL Spec. epoxy. Epoxy is chosen for superior mechanical properties and high temperature service. It also has superior resistance to aerospace fluids.

Laminations- Are M19, Silicon steel which is chosen for its excellent magnetic performance and relatively low cost. It is supplied with a C5 insulating finish which is bondable and weldable. We see almost no reason to use the Cobalt steels in new designs. The silicon steel must be well coated everywhere to provide adequate corrosion resistance.

Thread Inserts- Are locking helicoil type per MIL-Spec. They have a corrosion resistant coating, and a policy of always using the locking type prevents the need of secondary adhesives or lockwird for that purpose.

Splicing Tape- Is preferably Dupont Kapton. Kapton has the same chemistry as the magnet wire film thus offering a consistent insulation system. It has excellent fluids resistance and poke through resistance. In some heavy windings we are also using fiberglass fabric tape also available per MIL Spec.