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CMM Technology

Federal Manufacturing & Technologies

Robert C. Ward

KCP-613-8518

Published October 2008

Final Report on 706685

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Prepared under prime contract DE-ACO4-01AL66850 for the
United States Department of Energy

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A prime contractor with the United States Department of Energy under prime contract DE-ACO4-01AL66850.

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KCP-613-8518
Distribution Category UC-42

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Abstract

This project addressed coordinate measuring machine (CMM) technology and model-based engineering. CMM data analysis and delivery were enhanced through the addition of several machine types to the inspection summary program. CMM hardware and software improvements were made with the purchases of calibration and setup equipment and new model-based software for the creation of inspection programs. Kansas City Plant (KCP) personnel contributed to and influenced the development of dimensional metrology standards. Model-based engineering capabilities were expanded through the development of software for the tolerance analysis of piece parts and for the creation of model-based CMM inspection programs and inspection plans and through the purchase of off-the-shelf software for the tolerance analysis of mechanical assemblies. An obsolete database application used to track jobs in Precision Measurement was replaced by a web-based application with improved query and reporting capabilities. A potential project to address the transformation of the dimensional metrology enterprise at the Kansas City Plant was identified.

Summary

This project included several different activities, each of which addressed a technical gap in the areas of CMM technology and model-based technology.

In the area of inspection data analysis, a program was developed to summarize out-of-tolerance data for a group of parts, to improve the data's readability, and to automatically create a product scorecard and/or a spreadsheet that summarizes the out-of-tolerance data. The program uses inspection data files generated by a CMM to create a Microsoft Excel spreadsheet which, in turn, creates a product scorecard spreadsheet and/or an inspection summary spreadsheet. The product scorecard contains a benchmark sigma value, along with averages, standard deviations, and yields for each measurement key. The inspection summary contains out-of-tolerance values and ranges for each measurement key, detailed for each serial number of the group of parts.

Several hardware and software improvements were provided for CMMs in the Precision Measurement department. Calibration, probe setup, and part fixturing hardware was purchased. Calypso software and upgrades were purchased for seven different Zeiss CMMs, and training for a Precision Measurement CMM inspector/programmer was purchased for Zeiss Calypso Curve, and Planner, and Simulation software.

Three different reverse engineering software packages were evaluated, and the Raindrop Geomagic Studio software was determined to have superior capabilities and an easy-to-use interface.

Funded by this project, KCP personnel contributed to and influenced the development of the Dimensional Measuring Interface Standard (DMIS), the Dimensional Markup Language (DML), and the Exchange of Quality Measurement Process Plan (eQuiPP) standard. These standards provide standardized file formats for CMM inspection programs and for measurement results.

Model-based engineering capabilities were expanded through the development of Feature-Based Tolerancing (FBTol) software for the tolerance analysis of piece parts and of Feature-Based Measuring (FBMeas) software for the creation of model-based CMM inspection programs and inspection plans and through the purchase and use of CETOL Six Sigma, off-the-shelf software for the tolerance analysis of mechanical assemblies.

To improve operational efficiency in the Precision Measurement department, a web-based application that allows tracking of CMM inspection jobs was created. The application interfaces with an Oracle database and allows departmental personnel to record information about inspection jobs, including time spent programming, time spent inspecting, inspection job type, receiving and shipping dates and locations, and equipment used.

Discussion

Scope and Purpose

The compression of weapons program schedules, the increased use of parts suppliers, and the increased emphasis on work-for-others projects has led to the need to increase efficiency and improve the capabilities of coordinate measuring machines (CMMs) at the Kansas City Plant (KCP). In addition, large amounts of inspection data must be analyzed before disposition can be made on parts submitted to the Precision Measurement department. Reverse engineering software had been purchased, but it had not been evaluated. Also, CMM standards that are necessary to enable CMMs to reach their full potential are not yet released for use in industry. Model-based methods that increase throughput and improve quality have not been fully implemented in KCP's CMM operations.

This project addressed these needs by performing work in several areas. CMM hardware and software needs were assessed, and equipment and software were purchased to meet those needs. Programs were created and enhanced to automate and improve the analysis of the high volume of CMM inspection data. Three different reverse engineering software packages were evaluated. Funded by this project, KCP personnel contributed to and influenced the development of the Dimensional Measuring Interface Standard (DMIS), the Dimensional Markup Language (DML), and the Exchange of Quality Measurement Process Plan (eQuiPP) standard. Model-based engineering capabilities were expanded through the development of Feature-Based Tolerancing (FBTol), a software package used for the tolerance analysis of piece parts, Feature-Based Measuring (FBMeas), another software package used for the creation of CMM inspection plans, and the purchase of CETOL, off-the-shelf software used for tolerance analysis of mechanical assemblies that works directly with Pro/ENGINEER. An obsolete database application used to track jobs in Precision Measurement was replaced by the Inspection Job Management System, a web-based application with improved query and reporting capabilities.

Prior Work

ADAPT Project 706664, Advanced CMM Technology, performed work that was foundational for parts of this project. That project enabled the initial creation of the product scorecard and inspection summary programs, which were expanded and improved with this project. It also funded the purchase of three reverse engineering software packages, which were evaluated during this following project.

Activity

This project included several different activities, each of which addressed a technical gap in the areas of CMM technology and model-based technology.

<u>CMM Data Analysis</u>

Engineers and requesting inspection department personnel at the Kansas City Plant have been manually reviewing CMM inspection data for disposition of purchased and manufactured products. A program was developed to summarize out-of-tolerance data for a group of parts, to improve the data's readability, and to automatically create a product scorecard and/or a spreadsheet that summarizes the out-of-tolerance data. The program uses inspection data files generated by a CMM to create a Microsoft Excel spreadsheet which, in turn, creates a product scorecard spreadsheet and/or an inspection summary spreadsheet. The product scorecard contains a benchmark sigma value, along with averages, standard deviations, and yields for each measurement key. The inspection summary contains out-of-tolerance values and ranges for each measurement key, detailed for each serial number of the group of parts. See Figure 1 to view a pictorial representation of this process.

The program eliminates manual data entry, dramatically reduces the time to populate product scorecards, to review CMM inspection results, and to enter the data into reporting systems, and it improves the quality of the data.

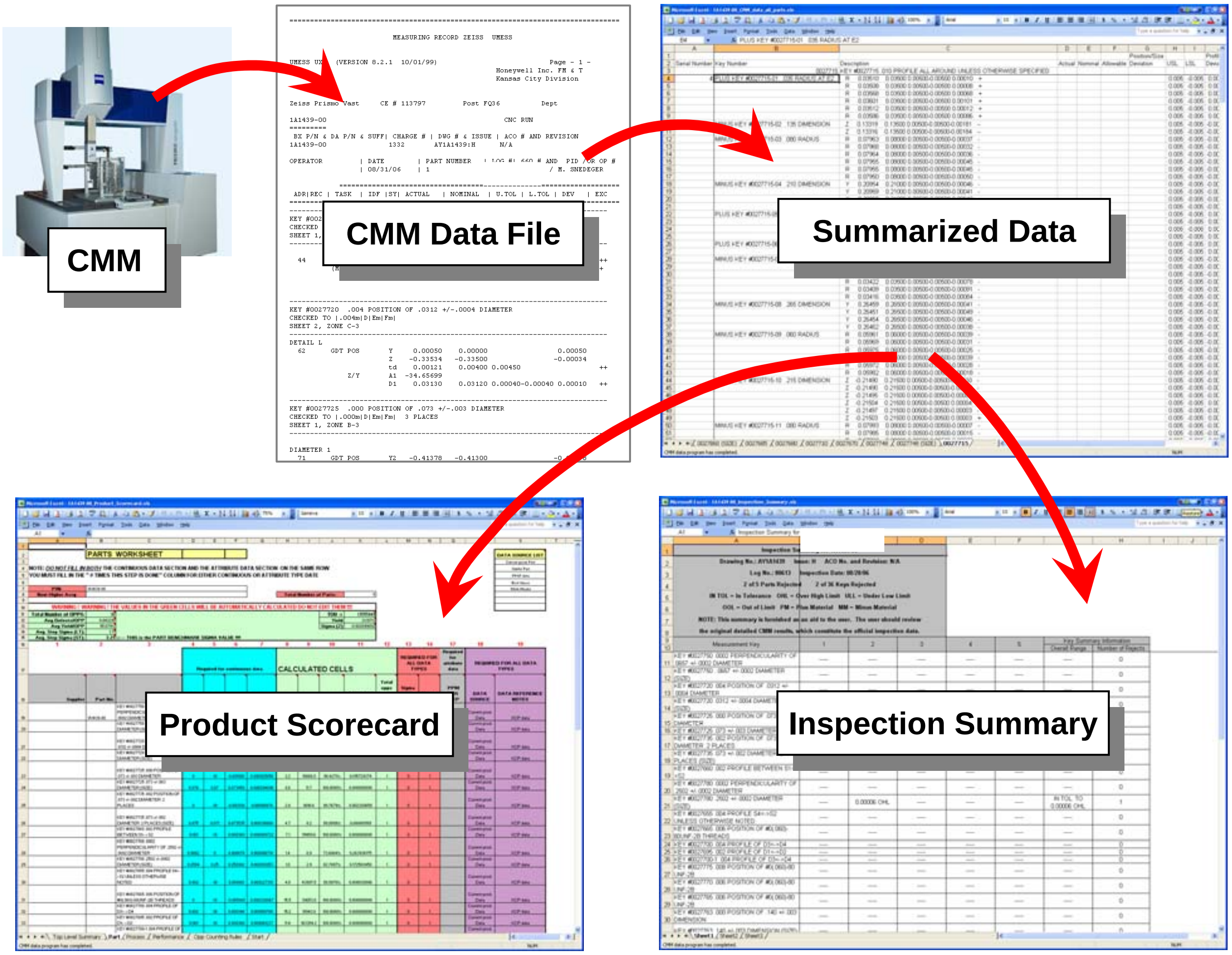
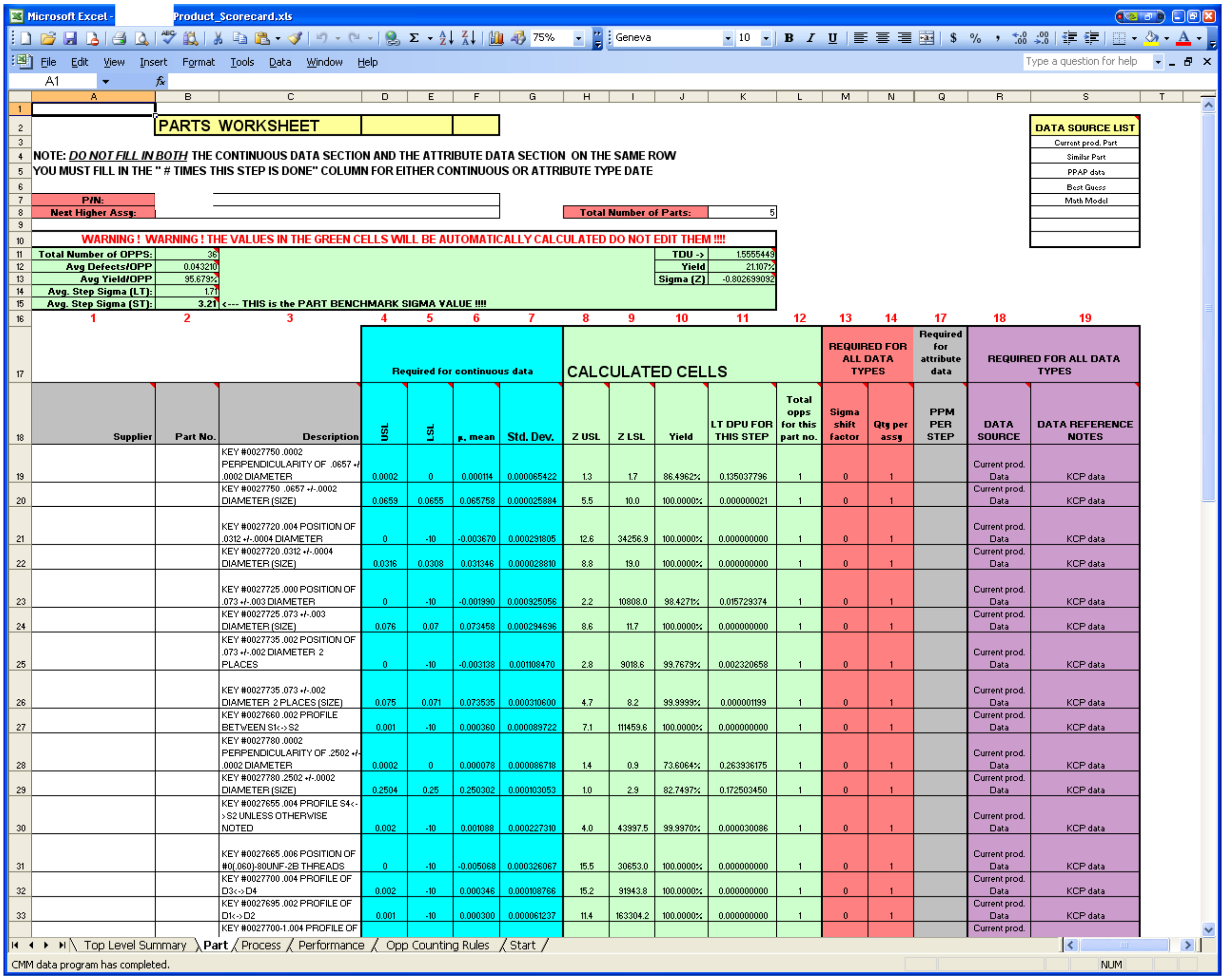


Figure 1: CMM Data Transfer Process

The CMM product scorecard and inspection summary creation processes were improved such that the two manual processes that took hours were replaced with a single automated process that takes a few minutes.

The product scorecard (Figure 2) calculates average, standard deviation, and yield percentage values for each inspection key measured in a group of parts, and a benchmark sigma value is provided that serves as a quality metric to help determine the disposition of the parts.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	17	18	19
Supplier	Part No.	Description	USL	LSL	μ mean	Std. Dev.	Z USL	Z LSL	Yield	LT DPU FOR THIS STEP	Total opps for this part no.	Sigma shift factor	Qty per assy	PPM PER STEP	DATA SOURCE	DATA REFERENCE NOTES
		KEY #0027750 .0002 PERPENDICULARITY OF .0657 +/- .0002 DIAMETER	0.0002	0	0.000114	0.000065422	1.3	1.7	86.4962%	0.135037796	1	0	1		Current prod. Data	KCP data
		KEY #0027750 .0657 +/-.0002 DIAMETER (SIZE)	0.0659	0.0655	0.065758	0.000025884	5.5	10.0	100.0000%	0.000000021	1	0	1		Current prod. Data	KCP data
		KEY #0027720 .004 POSITION OF .0312 +/-.0004 DIAMETER	0	-10	-0.003670	0.000291805	12.6	34256.9	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027720 .0312 +/-.0004 DIAMETER (SIZE)	0.0316	0.0308	0.031346	0.000028810	8.8	19.0	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027725 .000 POSITION OF .073 +/-.003 DIAMETER	0	-10	-0.001990	0.000925056	2.2	10808.0	98.4271%	0.015729374	1	0	1		Current prod. Data	KCP data
		KEY #0027725 .073 +/-.003 DIAMETER (SIZE)	0.076	0.07	0.073458	0.000294696	8.6	11.7	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027735 .002 POSITION OF .073 +/-.002 DIAMETER 2 PLACES	0	-10	-0.003138	0.001108470	2.8	9018.6	99.7679%	0.002320658	1	0	1		Current prod. Data	KCP data
		KEY #0027735 .073 +/-.002 DIAMETER 2 PLACES (SIZE)	0.075	0.071	0.073535	0.000310600	4.7	8.2	99.9999%	0.000001199	1	0	1		Current prod. Data	KCP data
		KEY #0027660 .002 PROFILE BETWEEN S1<->S2	0.001	-10	0.000360	0.000089722	7.1	111459.6	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027780 .0002 PERPENDICULARITY OF .2502 +/- .0002 DIAMETER	0.0002	0	0.000078	0.000086718	1.4	0.9	73.6064%	0.263936175	1	0	1		Current prod. Data	KCP data
		KEY #0027780 .2502 +/-.0002 DIAMETER (SIZE)	0.2504	0.25	0.250302	0.000103053	1.0	2.9	82.7497%	0.172503450	1	0	1		Current prod. Data	KCP data
		KEY #0027655 .004 PROFILE S4<->S2 UNLESS OTHERWISE NOTED	0.002	-10	0.001088	0.000227310	4.0	43997.5	99.9970%	0.000030086	1	0	1		Current prod. Data	KCP data
		KEY #0027665 .006 POSITION OF #0(.060)-80UNF-2B THREADS	0	-10	-0.005068	0.000326067	15.5	30653.0	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027700 .004 PROFILE OF D3<->D4	0.002	-10	0.000346	0.000108766	15.2	91943.8	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027695 .002 PROFILE OF D1<->D2	0.001	-10	0.000300	0.000061237	11.4	163304.2	100.0000%	0.000000000	1	0	1		Current prod. Data	KCP data
		KEY #0027700-1 .004 PROFILE OF													Current prod.	

Figure 2: Product Scorecard

The inspection summary (Figure 3) displays out-of-tolerance information for a group of parts in an easy-to-read, convenient manner for the engineer or requesting inspection department. Out-of-tolerance values are listed, including high and low values if a range of measurements were made for an inspection key. The data is displayed in a matrix consisting of measurement keys in the rows and part serial numbers in the columns. The information is summarized for the entire group of parts, including the number of keys rejected for a particular serial number, the overall range of out-of-tolerance values and the number of rejects for a particular measurement key, the number of parts rejected, and the number of keys rejected.

Inspection Summary for

Drawing No.: Issue: H ACO No. and Revision: N/A

Log No.: 80613 Inspection Date: 08/28/06

2 of 5 Parts Rejected 2 of 36 Keys Rejected

IN TOL = In Tolerance OHL = Over High Limit ULL = Under Low Limit

OOL = Out of Limit PM = Plus Material MM = Minus Material

NOTE: This summary is furnished as an aid to the user. The user should review the original detailed CMM results, which constitute the official inspection data.

Row	Measurement Key	1	2	3	4	5	Key Summary Information: Overall Range	Key Summary Information: Number of Rejects
11	KEY #0027750 .0002 PERPENDICULARITY OF .0657 +/-.0002 DIAMETER	-----	-----	-----	-----	-----	-----	0
12	KEY #0027750 .0657 +/-.0002 DIAMETER (SIZE)	-----	-----	-----	-----	-----	-----	0
13	KEY #0027720 .004 POSITION OF .0312 +/-.0004 DIAMETER	-----	-----	-----	-----	-----	-----	0
14	KEY #0027720 .0312 +/-.0004 DIAMETER (SIZE)	-----	-----	-----	-----	-----	-----	0
15	KEY #0027725 .000 POSITION OF .073 +/-.003 DIAMETER	-----	-----	-----	-----	-----	-----	0
16	KEY #0027725 .073 +/-.003 DIAMETER (SIZE)	-----	-----	-----	-----	-----	-----	0
17	KEY #0027735 .002 POSITION OF .073 +/-.002 DIAMETER 2 PLACES	-----	-----	-----	-----	-----	-----	0
18	KEY #0027735 .073 +/-.002 DIAMETER 2 PLACES (SIZE)	-----	-----	-----	-----	-----	-----	0
19	KEY #0027660 .002 PROFILE BETWEEN S1<->S2	-----	-----	-----	-----	-----	-----	0
20	KEY #0027780 .0002 PERPENDICULARITY OF .2502 +/-.0002 DIAMETER	-----	-----	-----	-----	-----	-----	0
21	KEY #0027780 .2502 +/-.0002 DIAMETER (SIZE)	-----	0.00006 OHL	-----	-----	-----	IN TOL. TO 0.00006 OHL	1
22	KEY #0027655 .004 PROFILE S4<->S2 UNLESS OTHERWISE NOTED	-----	-----	-----	-----	-----	-----	0
23	KEY #0027665 .006 POSITION OF #0(.060)-80UNF-2B THREADS	-----	-----	-----	-----	-----	-----	0
24	KEY #0027700 .004 PROFILE OF D3<->D4	-----	-----	-----	-----	-----	-----	0
25	KEY #0027695 .002 PROFILE OF D1<->D2	-----	-----	-----	-----	-----	-----	0
26	KEY #0027700-1 .004 PROFILE OF D3<->D4	-----	-----	-----	-----	-----	-----	0
27	KEY #0027775 .008 POSITION OF #0(.060)-80 UNF-2B	-----	-----	-----	-----	-----	-----	0
28	KEY #0027770 .006 POSITION OF #0(.060)-80 UNF-2B	-----	-----	-----	-----	-----	-----	0
29	KEY #0027765 .006 POSITION OF #0(.060)-80 UNF-2B	-----	-----	-----	-----	-----	-----	0
30	KEY #0027763 .000 POSITION OF .140 +/-.003 DIMENSION	-----	-----	-----	-----	-----	-----	0
	KEY #0027763 .140 +/-.003 DIMENSION (SIZE)	-----	-----	-----	-----	-----	-----	0

Sheet1 / Sheet2 / Sheet3

CMM data program has completed.

Figure 3: Inspection Summary

Work funded by this project expanded the capabilities of this program so that inspection data files generated by Zeiss CMMs running either UMESS or UMESS-LX software, Apollo CMMs running either MeasureMax or Metrologic software, and the OGP measuring machine can be used to create product scorecards and inspection summaries. See Figures 4 through 8.

```
================================================================================

                         MEASURING RECORD ZEISS  UMESS

UMESS UX   (VERSION 8.3.0  04-01-01)             HONEYWELL INC.  F M & T
                                                 Kansas City   Division



Zeiss Prismo Vast      CE#: 212115                Post FQ35  Dept.

1A0998-P01, .004 PROFILE                            CNC RUN
========================
 BX P/N & SUFF/DA P/N & SUFF|   CHARGE # |  DWG # & ISSUE  |  ACO & REVISION
1A0998-00-N4                                AY1A0998:E

OPERATOR          | DATE        | PART NUMBER   |  LOG # |  660 # AND / OR II GRP
                  | 06/04/08    |                  50498                OP.0030

================================================================================
 ADR|REC | TASK   | IDF |SY| ACTUAL    | NOMINAL   | U.TOL | L.TOL | DEV   | EXC
================================================================================
   1      WP same as WPOX     14.4766
                       Y    -46.3645
                       Z    -10.6859
          SPACE        A      0.0073
          PLANE        A     -0.0000   ABOUT SPACE AXIS   Z

   2      WP same as WPOX     14.4766
                       Y    -46.3645
                       Z    -10.6859
          SPACE        A      0.0073
          PLANE        A     -0.0000   ABOUT SPACE AXIS   Z

   3      POINT        X      2.9804

   4      ZEROP        X      2.9804

   5      WP same as WPOX     17.4570
                       Y    -46.3645
                       Z    -10.6859
          SPACE        A      0.0073
          PLANE        A     -0.0000   ABOUT SPACE AXIS   Z

   6      POINT        Z     -0.0064

   7      WP same as WPOX     14.4766
                       Y    -46.3645
                       Z    -10.6859
          SPACE        A      0.0073
          PLANE        A     -0.0000   ABOUT SPACE AXIS   Z

   8      REROTATE     A    -30.0000ABOUT SPACE AXIS Z

   9      WP same as WPOX     35.7193
                       Y    -32.9146
                       Z    -10.6859
          SPACE        A      0.0073
          PLANE        A     30.0000   ABOUT SPACE AXIS   Z
```

Figure 4: Zeiss UMESS Data File (Page One of Many)

```
================================================================================
                          MEASURING RECORD ZEISS  UMESS
UMESS-LX   (VERSION 1.6.0 / DEC, 2002)                        HONEYWELL FM&T
                                                              KANSAS CITY PLANT

ZEISS PRISMO 7 S-ACC VAST          CE# 211754         POST FL34  DEPT.

CM423756-000:B                                       CNC RUN
==============
 BX P/N & SUFF/DA/ P/N & SUFF| CHARGE # | DWG # & ISSUE |  ACO & REVISION |
                                           423756:C

OPERATOR         | DATE         | PART NUMBER   | LOG # | 660 # AND/OR II GROUP
                 | 11/14/07     | #1173          11 0343             OPER.

================================================================================
 ADR|REC | TASK   | IDF |SY| ACTUAL    | NOMINAL   | U.TOL | L.TOL | DEV    | EXC
================================================================================
   1      WP same as WPOX    695.5974
                       Y    -980.7329
                       Z    -415.3638
          SPACE        A       0.2791
          PLANE        A      -0.0000   ABOUT SPACE AXIS   X

   2      SURFACE      X       0.0060
              Y/X      A1     -0.0312
              Z/X      A2     -0.0547
      24P S/MIN/MAX            0.0020        (8) -0.0031     (3)  0.0028


-----------------------------------------------------------------------------
KEY #0090009
|0.1|FLATNESS|  OF -A-
REQUIREMENT #9
LOCATION 1C3
-----------------------------------------------------------------------------

   3      GDT FLT #9   t       0.0059     0.1000                            +

   4      ROTATE SPACE  A      0.3355

   5      ZEROP        X       0.0060

   6      WP same as WPOX    696.5333
                       Y    -980.3545
                       Z    -414.6982
          SPACE        A       0.3355
          PLANE        A      -0.0000   ABOUT SPACE AXIS   X

   7      CIRCLEI      Y       0.0008
                       Z       0.0233
                       D      19.0025
      13P S/MIN/MAX            0.0006        (4) -0.0009     (5)  0.0008

   8      ZEROP        Y       0.0008
                       Z       0.0233

   9      WP same as WPOX    696.5333
```

Figure 5: Zeiss UMESS-LX Data File (Page One of Many)

```
--------------------------------------------------------------------------
     Part Program: 344591
    Part Serial #:                              Date/Time: 07/01/2008 16:19:45
        Inspector:                                   CMM: CMM1
--------------------------------------------------------------------------

GIDDINGS & LEWIS MEASUREMAX VERSION 6.02
Partnumber=
Partname=SUPPORT CX (U)
Drawings=AY344591:U
Insptype=100%
Item/PID=           Op Sequence=155
ACO'S & REV.=□□□□□□□□□□□□□□□
CE #=81282
KCD 660 #=
LOG #=060551


KEY 155010  2.000  +/- .020 DIMENSION         ZONE 1/B-1

        NOMINAL      ACTUAL          DEV              OUT-TOL

DS        2.000       2.000        0.000                 -

DS        2.000       2.000        0.000                 +

DS        2.000       2.001        0.001                 +

DS        2.000       2.002        0.002                 +

DS        2.000       2.001        0.001                 +

DS        2.000       2.000        0.000                 +

DS        2.000       2.001        0.001                 +

DS        2.000       2.001        0.001                 +

DS        2.000       2.000        0.000                 -

DS        2.000       2.002        0.002                 +

KEY 155020  5.00  +/- .03 DIAMETER                 ZONE 1/B-4

        NOMINAL      ACTUAL          DEV              OUT-TOL

X         0.000       0.003        0.003                 +
Y         0.000       0.002        0.002                 +
DI        5.000       4.986       -0.014                 --


KEY 155030  10.515 +.010/-.015 DIAMETER          ZONE 1/B-4


        NOMINAL      ACTUAL          DEV              OUT-TOL

X        0.0000      0.0009       0.0009                 +
Y        0.0000     -0.0002      -0.0002                 -
```

Figure 6: Apollo MeasureMax Data File (Page One of Many)

```
QT1A1067P1-000_C_6074_001.TXT 23 Jul 2008 07:23
*******************************************************************************
           Feat   Val        Act        Nom    Tol+    Tol-     Dev  Out of Tol
*******************************************************************************
-------------------------------------------------------------------------------

     Part Program:
        Directory: C:\Mdrive\Prgms\Provein\   Date/Time: 2008/07/23 07:23
        Inspector:                                 CMM: CE_82951
    Part Serial #:
-------------------------------------------------------------------------------

-------------------------------------------------------------------------------

     LOG NUMBER : 2008070361
     PID NUMBER :
     PART NUMBER:
     PART SUFFIX: 00
     PART NAME  : Housing, Full Machined
     CLASSIFICATION: UNCLASSIFIED
     DRAWING/ISS: AY1A1067 Iss K
     ML/ISSUE  : 1A1067 Iss J
     ACO NUMBER: N/A
     WORK TYPE : PRODUCTION
     EXECUTIVE SOFTWARE : MetrologXG v8.00
-------------------------------------------------------------------------------


NOTES:
Letter(s) at end of Part Program No. = Issue of Part Program
Issues of DRAWING and ML = Issues when Part Program was released

=================================================
           PM_PARTNO:
=================================================

-----------------------------------------------------------
GROUP/KEY NUMBER = 503
-----------------------------------------------------------

=====================================================
     .005 Symmetry of .188 +/- .001 Dia. Datum -C-
    ********* Size Engineering Info Only *********
                | .005m | D | Bm |
                Sheet 2, Zone D-1
=====================================================

         CIRC2A     X    -0.0000     0.0000  9.0000 -9.0000 -0.0000
         CIRC2A  DIAM     0.1880     0.1880  0.0010 -0.0010 -0.0000
        TOL3001  PTOL     0.0001     0.0000  0.0060          0.0001

        CIRC25A     X     0.0000     0.0000  9.0000 -9.0000  0.0000
        CIRC25A  DIAM     0.1880     0.1880  0.0010 -0.0010 -0.0000
        TOL3003  PTOL     0.0001     0.0000  0.0060          0.0001
-----------------------------------------------------------
GROUP/KEY NUMBER = 101
-----------------------------------------------------------

=====================================================
            4.797 +/- .003 Dia. Datum -B-
```

Figure 7: Apollo Metrologic Data File (Page One of Many)

```
                                                                         Page:    1
================================================================================
Routine Name                                      Run #      Date & Time
================================================================================
gt257804-000-e.rtn                                    1 Thu Jul 06 09:13:26 2006
================================================================================
CE211741
P/N:              FLEX CIRCUIT LONG (U)
INSPECTED PER:  DRWG
INSPECTED BY:
OGP LOG# 3878                                 SAMPLE# 8147
================================================================================
Feature       Unit   Nominal     Actual      Tolerances       Deviation   Exceeded
================================================================================

Step 49 - PART INSPECTED WITH DATUM -A- DOWN & PART# FACING UP
Result         mm  +000.0000  +000.0000                       +000.0000

Step 50 - KEY001 0.100 PROF|A|S|T|3X
Result         mm  +000.0000  +000.0000                       +000.0000

Step 51 - KEY001-01A 0.25 DIM (TOP EDGE PAD1) +DEV=+MAT'L
Profile +      mm             +000.0071  +00.0250             +000.0071    ++
Profile -      mm             -000.0024             -00.0750  -000.0024    -

Step 52 - KEY001-02A 0.25 FULL RAD (PAD1) +DEV=+MAT'L
Profile +      mm             +000.0000  +00.0250             +000.0000
Profile -      mm             -000.0308             -00.0750  -000.0308    --

Step 53 - KEY001-03A -0.25 DIM (BOTTOM EDGE PAD1) +DEV=+MAT'L
Profile +      mm             +000.0029  +00.0250             +000.0029    +
Profile -      mm             -000.0039             -00.0750  -000.0039    -

Step 55 - KEY001-04A 0.25 RAD(BOTTOM CORNER PAD1) +DEV=+MAT'L
R Location     mm  +000.2500  +000.2405  +00.0250   -00.0750  -000.0095    -

Step 56 - KEY001-05A 0.25 RAD (TOP CORNER PAD1) +DEV=+MAT'L
R Location     mm  +000.2500  +000.2399  +00.0250   -00.0750  -000.0101    -

Step 67 - KEY001-01B 0.25 DIM (TOP EDGE PAD2) +DEV=+MAT'L
Profile +      mm             +000.0045  +00.0250             +000.0045    +
Profile -      mm             -000.0015             -00.0750  -000.0015    -

Step 68 - KEY001-02B 0.25 FULL RAD (PAD2) +DEV=+MAT'L
Profile +      mm             +000.0000  +00.0250             +000.0000
Profile -      mm             -000.0296             -00.0750  -000.0296    --

Step 69 - KEY001-03B -0.25 DIM (BOTTOM EDGE PAD2) +DEV=+MAT'L
Profile +      mm             +000.0162  +00.0250             +000.0162    +++
Profile -      mm             +000.0000             -00.0750  +000.0000

Step 71 - KEY001-04B 0.25 RAD (BOTTOM CORNER PAD2) +DEV=+MAT'L
R Location     mm  +000.2500  +000.2387  +00.0250   -00.0750  -000.0113    -

Step 72 - KEY001-05B 0.25 RAD (TOP CORNER PAD2) +DEV=+MAT'L
R Location     mm  +000.2500  +000.2331  +00.0250   -00.0750  -000.0169    -

Step 90 - KEY001-01C 0.25 DIM (TOP EDGE PAD3) +DEV=+MAT'L
Profile +      mm             +000.0013  +00.0250             +000.0013    +
Profile -      mm             -000.0037             -00.0750  -000.0037    -
```

Figure 8: OGP Data File (Page One of Many)

CMM Hardware and Software Improvements

Hardware Improvements

Hardware purchases totaling $17K were made with funds from this project. A calibration sphere was purchased for the OGP measuring machine, and a vacuum pump was purchased to assist in the fixturing of foam parts for inspection. In addition, a probe setup aid was purchased for use on any of several Zeiss CMMs, and a set of probe adapter plates was purchased for the Zeiss CARAT CMM.

Software Improvements

Project funds totaling $32K were used to purchase software in support of KCP's CMM operation. Calypso software (Figure 9) and upgrades were purchased for seven different Zeiss CMMs. Training for a Precision Measurement CMM inspector/programmer was purchased for Zeiss Calypso Curve, and Planner, and Simulation software.

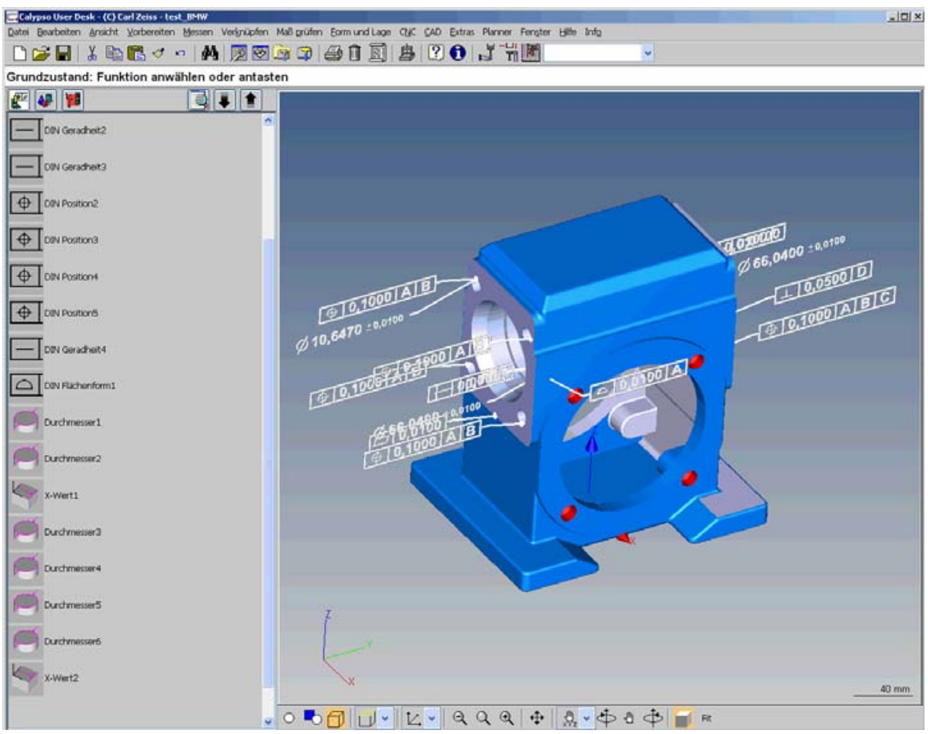


Figure 9: Zeiss Calypso Software

The Calypso Planner software (Figure 10) enables off-line programming of Zeiss CMMs using solid models. Solid models of the Zeiss CMM, fixtures, and probe setups are used with a solid model of one of KCP's parts, and an inspection program can be created in a user-friendly and intuitive virtual environment.

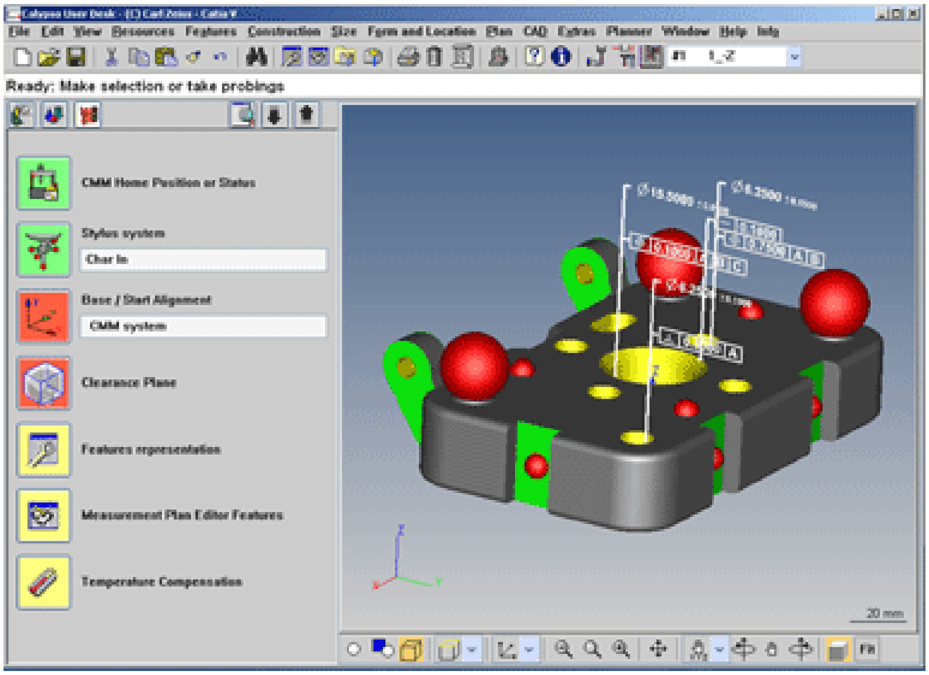


Figure 10: Zeiss Calypso Planner Software

The Calypso Simulation software (Figure 9) allows the programmer to test an inspection program in the virtual environment, so that errors are kept to a minimum and the program can be optimized. These methods reduce the time required to create part inspection programs, and they free up CMMs to measure more parts.

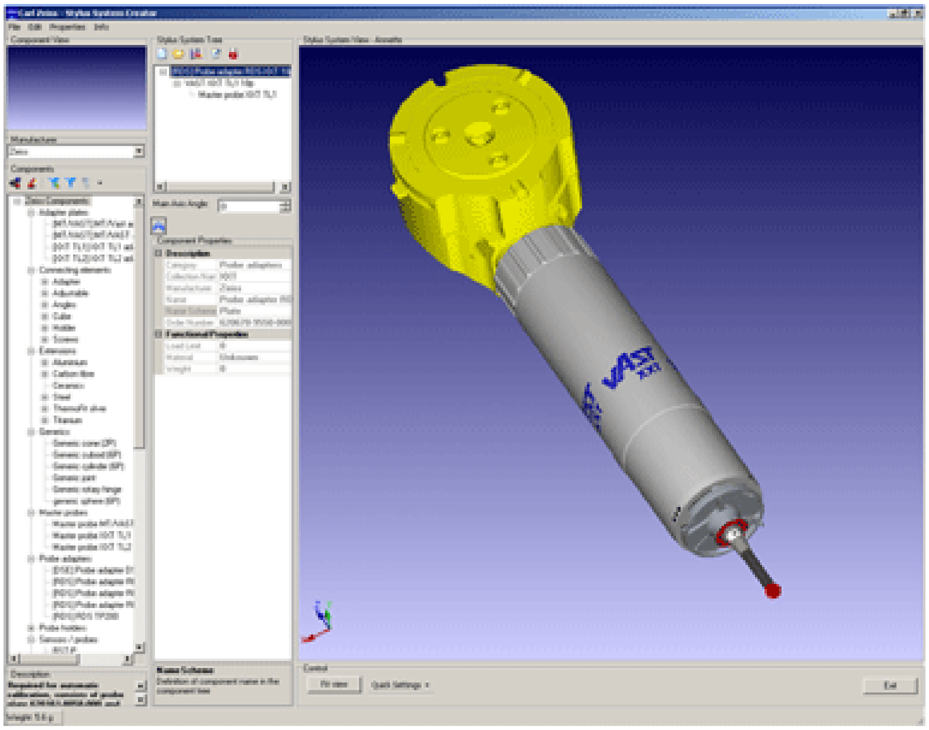


Figure 11: Zeiss Calypso Simulation Software

Reverse Engineering Software Evaluation

Three different reverse engineering software packages were evaluated. The Raindrop Geomagic Studio software package (Figure 12) was determined to have superior capabilities and an easy-to-use interface. $13K was allocated for labor expended in this evaluation.

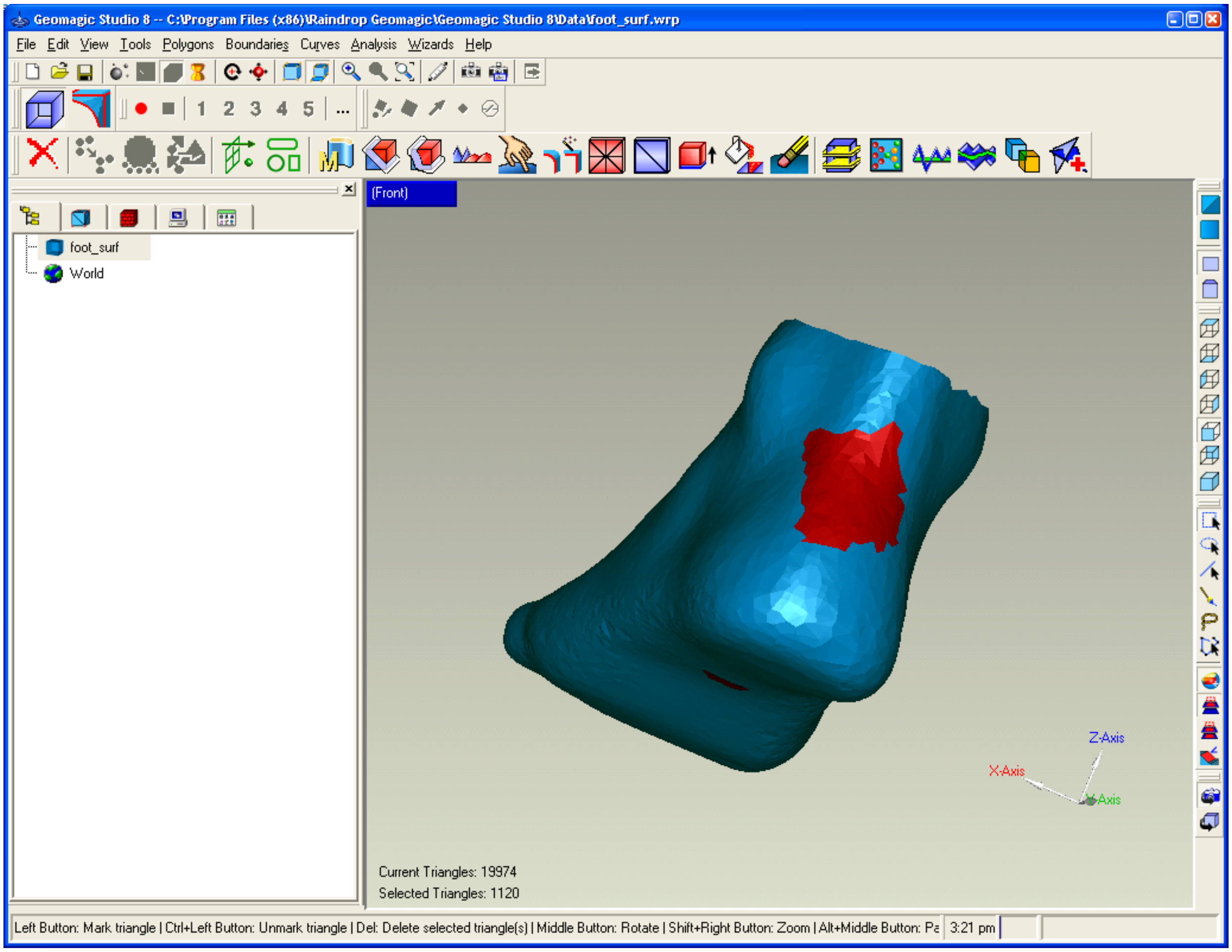


Figure 12: Raindrop Geomagic Studio Reverse Engineering Software

<u>**Dimensional Metrology Standards**</u>

Funded by this project, KCP personnel contributed to and influenced the development of the Dimensional Measuring Interface Standard (DMIS), the Dimensional Markup Language (DML), and the Exchange of Quality Measurement Process Plan (eQuiPP) standard. DMIS (Figure 13) is a standard file format used to run coordinate measuring machines and to translate inspection programs from one data format to another. DML is an emerging standard that provides a common method for storing measurement results. This project funded $81K for labor, $12K for materials, and $12K for travel in support of this standards work.

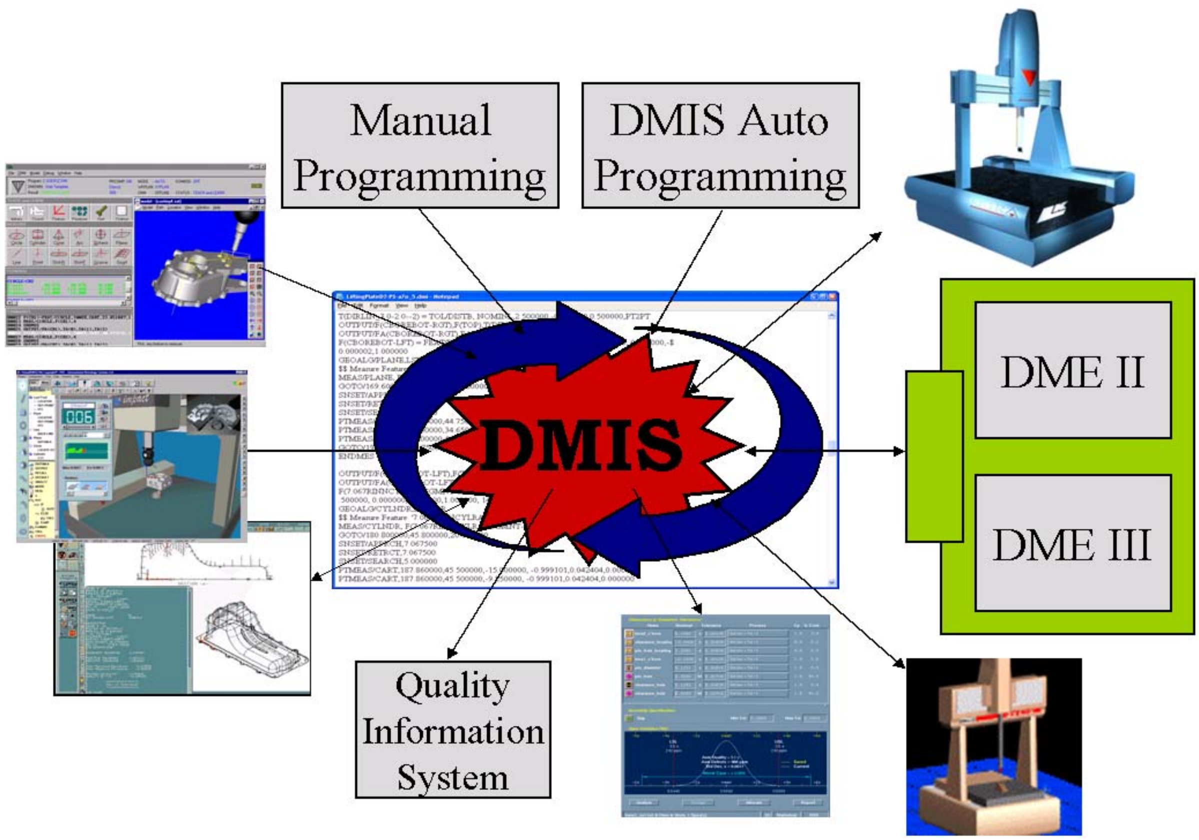


Figure 13: Dimensional Measuring Interface Standard (DMIS)

Model-Based Enterprise

This project funded work for the development of Feature-Based Tolerancing (FBTol), model-based software that analyzes piece parts for complete and unambiguous tolerance schemes (Figure 14), and Feature-Based Measuring (FBMeas), which generated CMM inspection programs and helps create intelligent inspection plans.

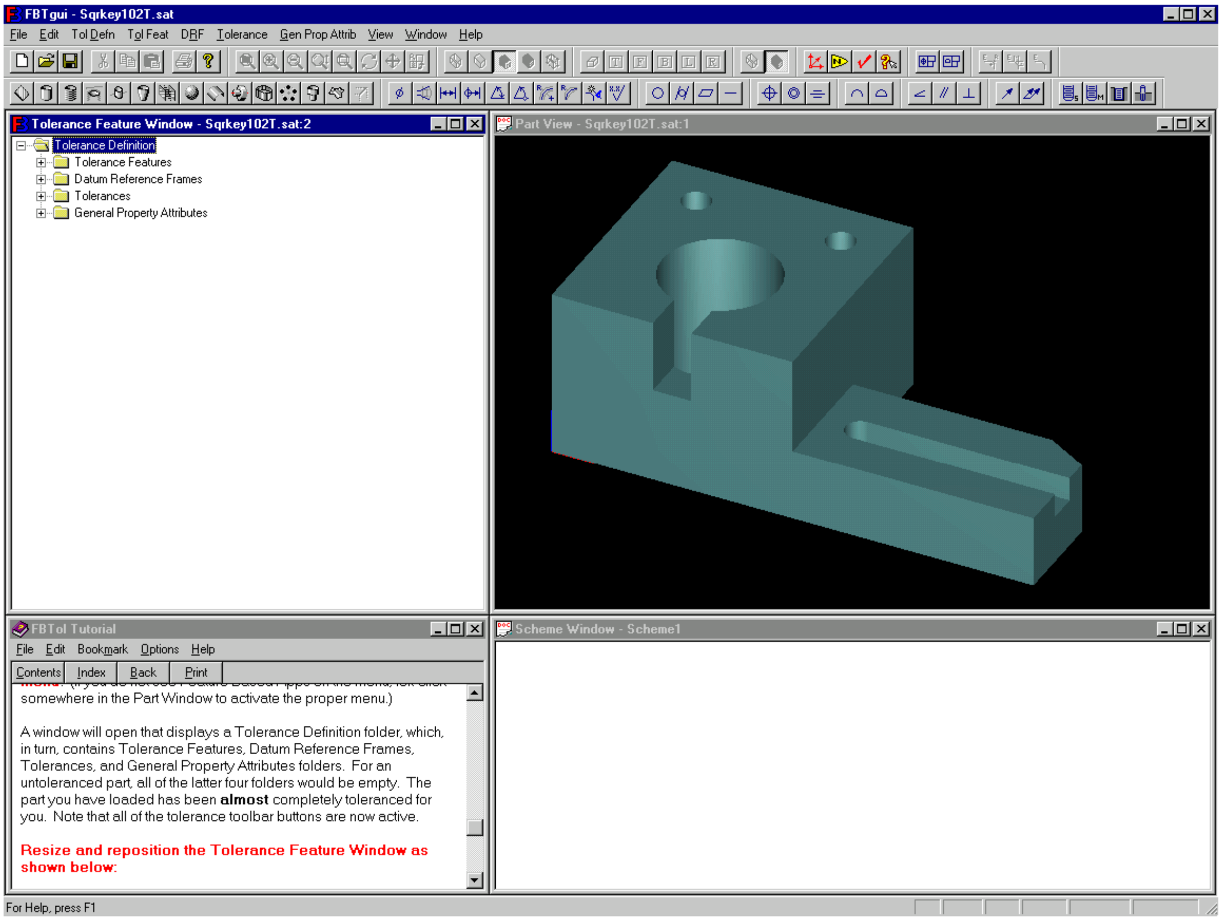


Figure 14: Feature-Based Tolerancing (FBTol)

Off-the-shelf software, CETOL Six Sigma (Figure 15), was purchased and used for the tolerance stackup analysis of mechanical assemblies. The tool allows the user to define suspected trouble areas in an assembly and use sophisticated algorithms to determine if potential interference conditions exist, and if those conditions do exist, it identifies methods to eliminate the problems. The product works concurrently with Pro/ENGINEER.

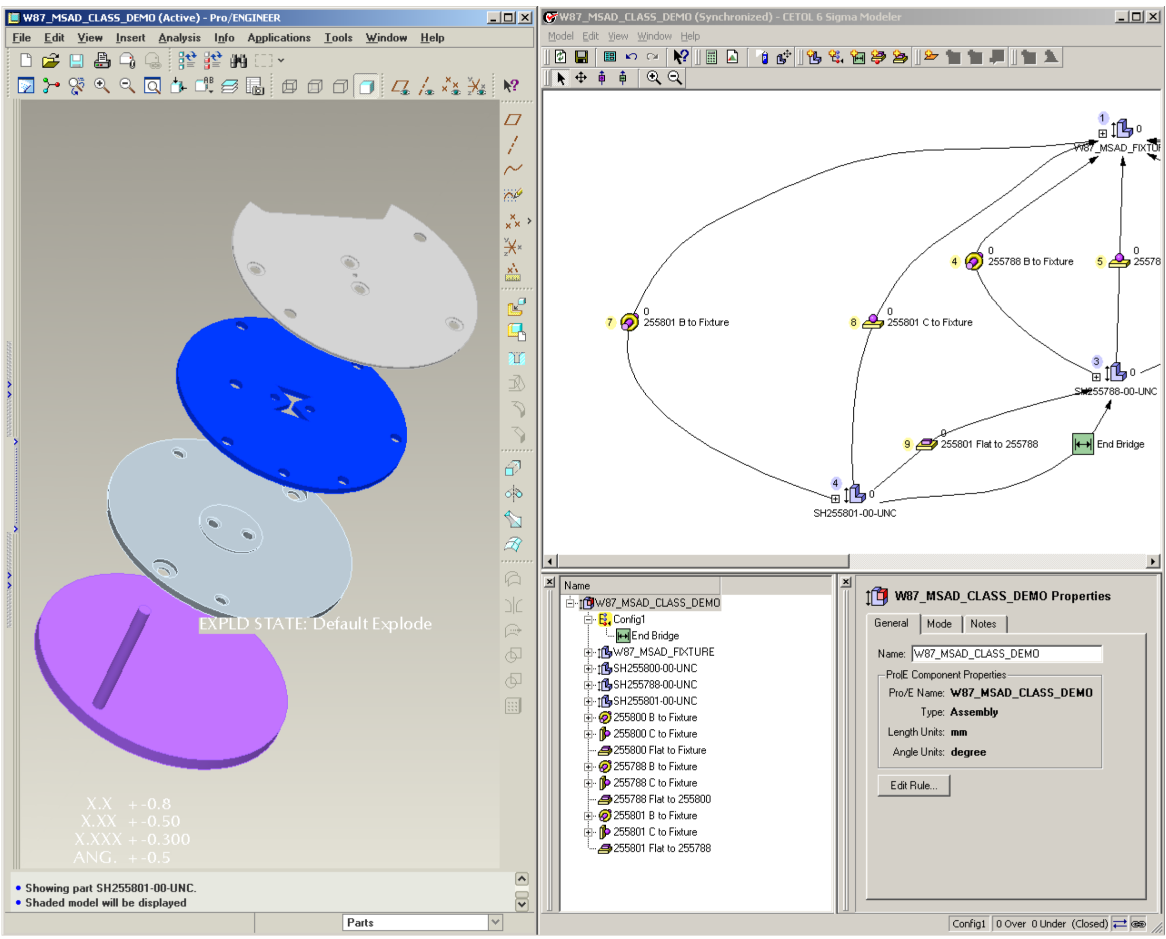


Figure 15: CETOL Six Sigma

Precision Measurement Database

A web-based application that allows tracking of CMM inspection jobs in the Precision Measurement department was created. The application interfaces with an Oracle database and allows department personnel to record information about inspection jobs, including time spent programming, time spent inspecting, inspection job type, receiving and shipping dates and locations, and equipment used. Figure 16 shows the system's main menu.

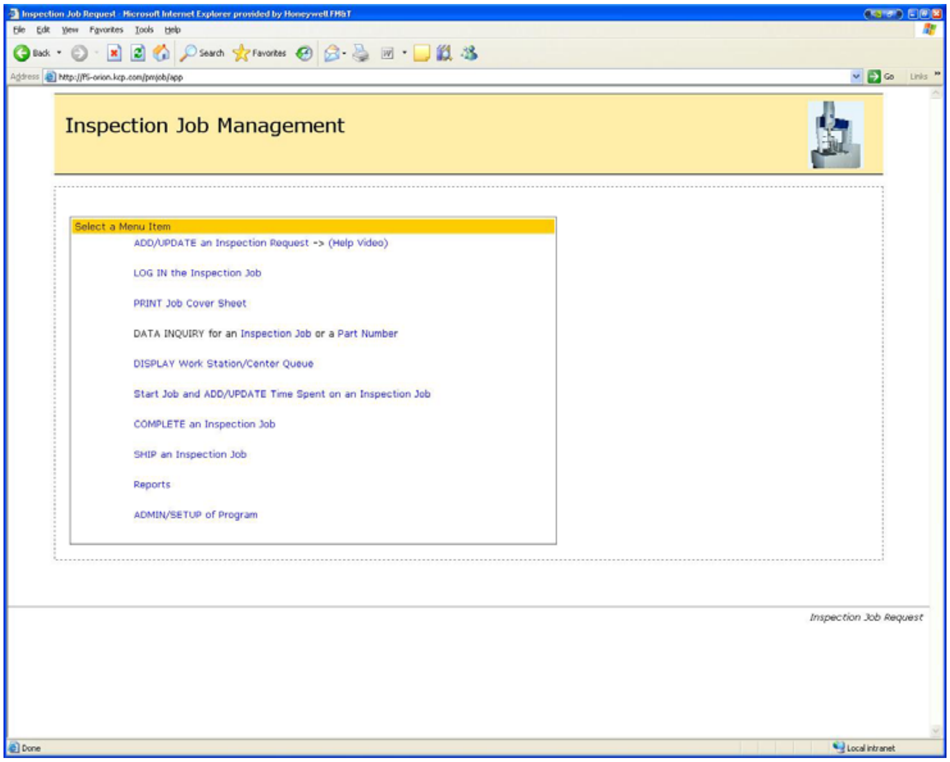
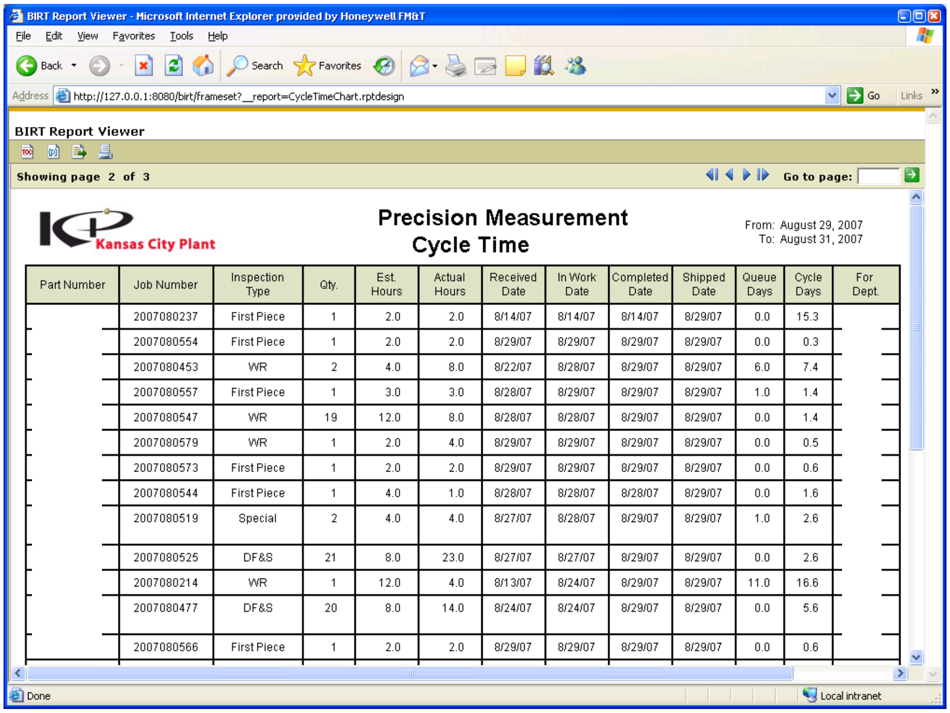


Figure 16: Job Management System: Main Menu

The new application includes customized reports and charts that allow the user to view such things as cycle time (Figures 17 and 18) and average monthly estimated and actual inspection time (Figure 19). This system allows inspectors and the department manager to more efficiently manage their inspection work and to provide more accurate and timely information to their customers. This project provided $231K in funding for the labor required to develop, deploy, and maintain this application.



BIRT Report Viewer

Showing page 2 of 3

Kansas City Plant

Precision Measurement
Cycle Time

From: August 29, 2007
To: August 31, 2007

Part Number	Job Number	Inspection Type	Qty.	Est. Hours	Actual Hours	Received Date	In Work Date	Completed Date	Shipped Date	Queue Days	Cycle Days	For Dept.
	2007080237	First Piece	1	2.0	2.0	8/14/07	8/14/07	8/14/07	8/29/07	0.0	15.3	
	2007080554	First Piece	1	2.0	2.0	8/29/07	8/29/07	8/29/07	8/29/07	0.0	0.3	
	2007080453	WR	2	4.0	8.0	8/22/07	8/28/07	8/29/07	8/29/07	6.0	7.4	
	2007080557	First Piece	1	3.0	3.0	8/28/07	8/29/07	8/29/07	8/29/07	1.0	1.4	
	2007080547	WR	19	12.0	8.0	8/28/07	8/28/07	8/29/07	8/29/07	0.0	1.4	
	2007080579	WR	1	2.0	4.0	8/29/07	8/29/07	8/29/07	8/29/07	0.0	0.5	
	2007080573	First Piece	1	2.0	2.0	8/29/07	8/29/07	8/29/07	8/29/07	0.0	0.6	
	2007080544	First Piece	1	4.0	1.0	8/28/07	8/28/07	8/28/07	8/29/07	0.0	1.6	
	2007080519	Special	2	4.0	4.0	8/27/07	8/28/07	8/29/07	8/29/07	1.0	2.6	
	2007080525	DF&S	21	8.0	23.0	8/27/07	8/27/07	8/29/07	8/29/07	0.0	2.6	
	2007080214	WR	1	12.0	4.0	8/13/07	8/24/07	8/29/07	8/29/07	11.0	16.6	
	2007080477	DF&S	20	8.0	14.0	8/24/07	8/24/07	8/29/07	8/29/07	0.0	5.6	
	2007080566	First Piece	1	2.0	2.0	8/29/07	8/29/07	8/29/07	8/29/07	0.0	0.6	

Figure 17: Job Management System: Cycle Time Table

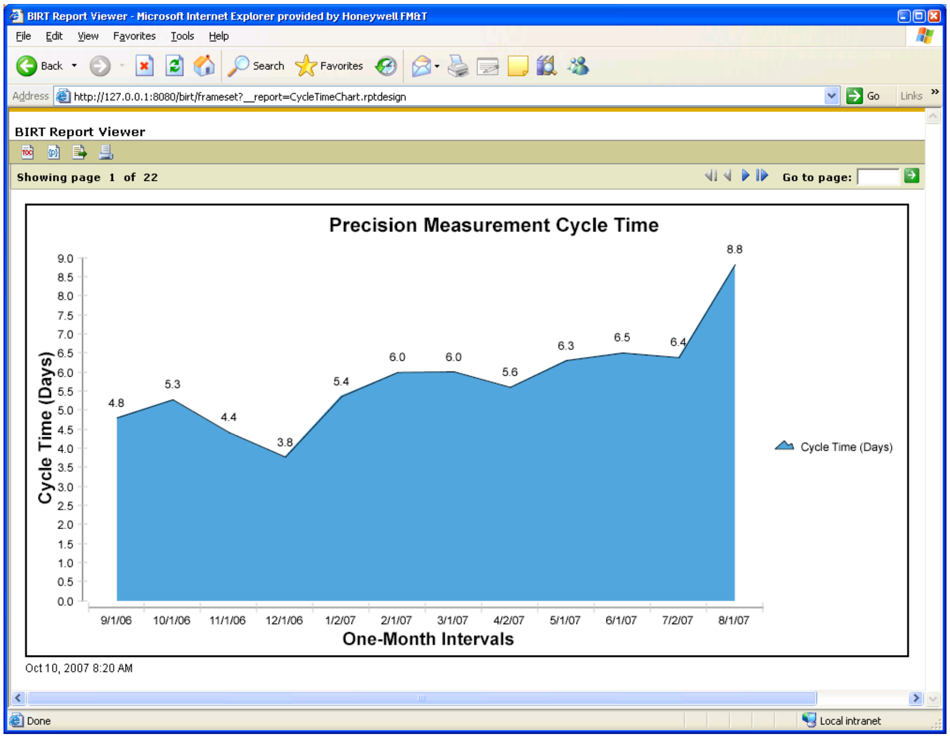


Figure 18: Job Management System: Cycle Time Chart

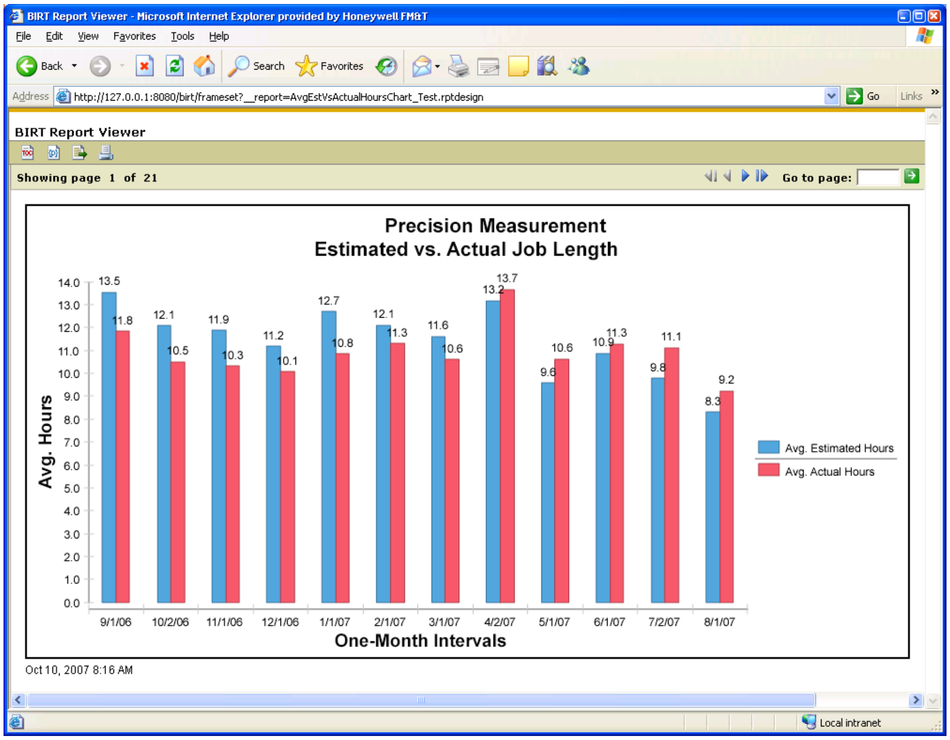


Figure 19: Job Management System: Estimated Vs. Actual Time

Accomplishments

CMM hardware and software needs were assessed, and equipment and software were purchased to meet those needs. Programs were created and enhanced to automate and improve the analysis of the high volume of CMM inspection data. Three different reverse engineering software packages were evaluated. Funded by this project, KCP personnel contributed to and influenced the development of the Dimensional Measuring Interface Standard (DMIS), the Dimensional Markup Language (DML), and the Exchange of Quality Measurement Process Plan (eQuiPP) standard. Model-based engineering capabilities were expanded through the development of Feature-Based Tolerancing (FBTol), a software package used for the tolerance analysis of piece parts, Feature-Based Measuring (FBMeas), another software package used for the creation of CMM inspection plans, and the purchase of CETOL, off-the-shelf software used for tolerance analysis of mechanical assemblies that works directly with Pro/ENGINEER. An obsolete database application used to track jobs in Precision Measurement was replaced by the Inspection Job Management System, a web-based application with improved query and reporting capabilities.

Future Work

Work remains to be done in several areas of CMM and model-based technology. The generation of product scorecards and inspection summaries should be fully automated such that it happens in the background, with no intervention from the inspectors running the CMMs. The inspection data files should be placed in a public folder that can be accessed by engineers and other inspection departments as needed. Inspection data from all of the various makes of CMMs should be standardized, and this standardization should ultimately be in the format of the Dimensional Markup Language. The CMMs in the Precision Measurement department are not yet networked in either the classified or unclassified environments. When this is accomplished, common network directories should be created in these environments for the storage of CMM inspection programs and inspection results files. Data analysis capabilities should also be extended to KCP suppliers with their own CMMs. KCP's influence and involvement with the various CMM-related standards should be continued. The Inspection Job Management System will be discontinued with the rollout of Solumina, the replacement for the current MES system, and work will be required to migrate the old system's capabilities and legacy data into the new system. Work needs to be initiated to transform KCP's dimensional metrology enterprise to an efficient, seamless system where product design information, CMM inspection programs, inspection data, and results analysis are available from an engineer's desktop.