Aspects of the SSR1 Coldmass Assembling

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23 September, 2016

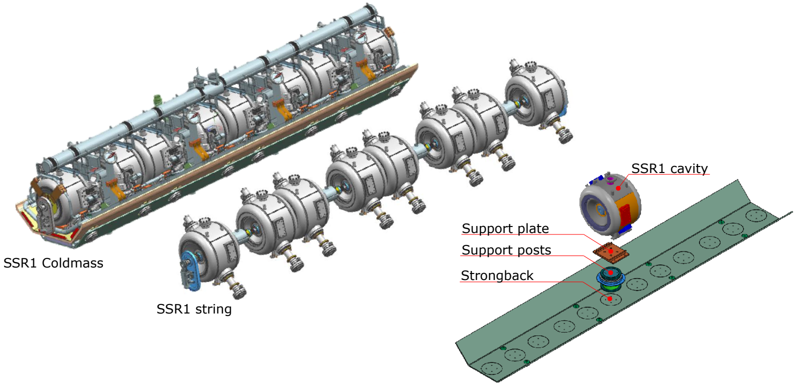
Outline

PIP-II project

SSR1 Cryomodule

This project consists in upgrading the existing linear accelerator (LINAC) at Fermiab to higher energies

- The SSR1 coldmass is a section of PIP-II project



Assembling procedure SSR1 coldmass

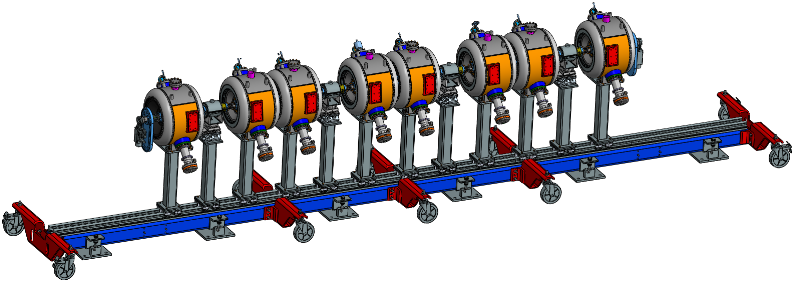
Main steps

In this work four main steps of the SSR1 coldmass asembling have been analyzed:

- String Assembly
- String Stiffening
- String Lifting
- String Alignment

Step 1

The SSR1 string is assembled in the cleanroom and supported by rail system

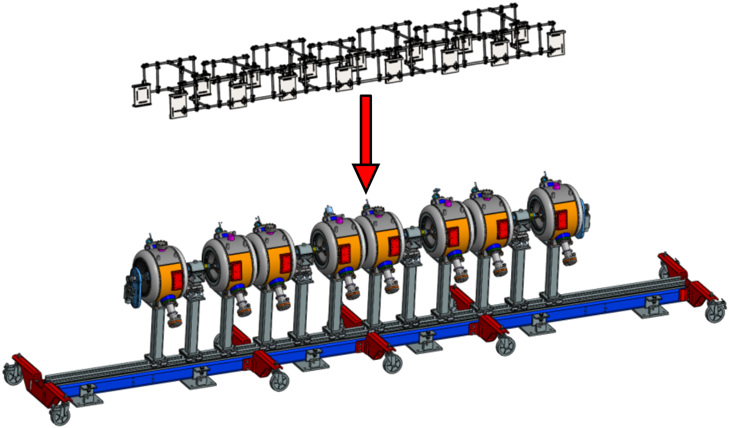


Assembling procedure SSR1 coldmass

String Stiffening

Step 2

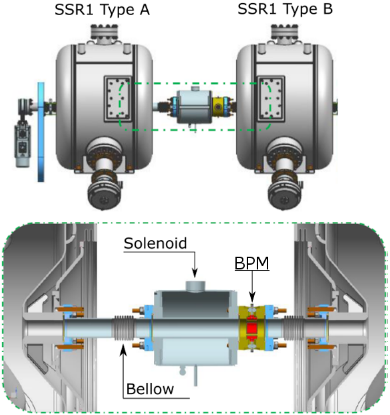
Stiffening of the SSR1 string assembly with an external frame



Stiffening frame

Introduction

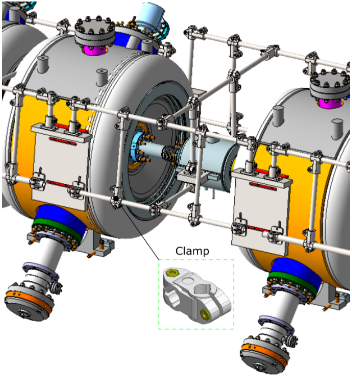
Since the cavity-cavity link is not rigid, before any handling operation it is necessary to stiff the string with an external structure.



Expansion joints (Bellows) are inserted between cavity-magnet and BPM-cavity to compensate thermal shrinkage

It is necessary to protect the Bellows from undesired loads, especially form torsional loads

The conceptual design is a truss beam tube structure connected to each cavity and solenoid.



- Structure modularity

  It is easy to increase the number of the elements or modify their relative position to maximize the stiffness

- Adjustable system

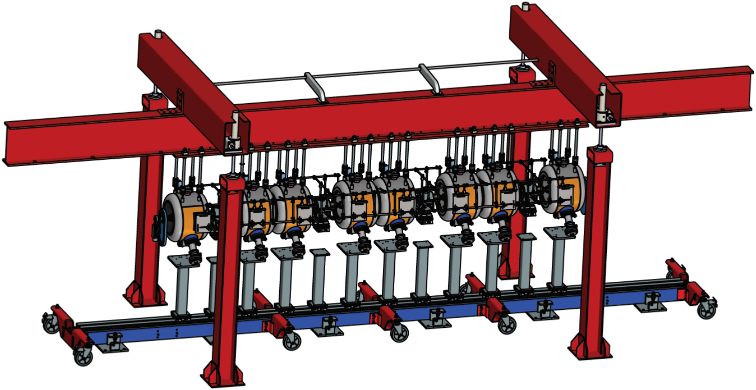
  Using slotted holes and connecting tubes by clamp, it is possibile to compensate manufacturing/assembly misalignments

Assembling procedure SSR1 coldmass

String Lifting

Step 3

The string is lifted from the rail system to be mounted on the coldmass support (strongback)



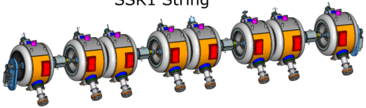
Lifting tooling
Concept

- Four points lifting structure
- Standard beam shape
- Mechanical lifting system
- Bolted connection to facilitate the assembly and transportation

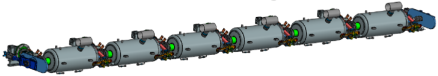
Lifting tooling
Requirements

- SSR1 and HB 650 strings (PIP-II project) need to be lifted

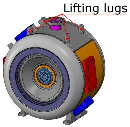
SSR1 String



HB 650 String



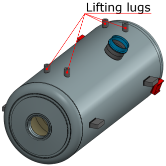
- String lifted by the lifting lugs



SSR1 cavity

- Maximum deflection allowed: $1mm$

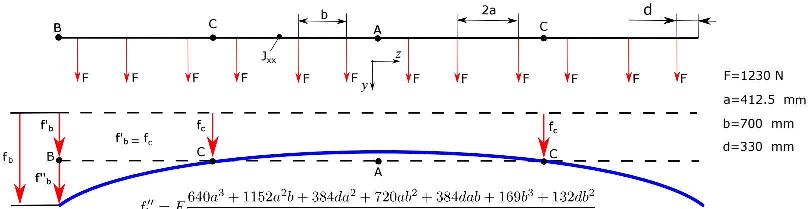
- Loads
  - SSR1 String weight: $1250kg$
  - HB 650 String weight: $1500kg$



HB 650 cavity

Lifting tooling
Structural design

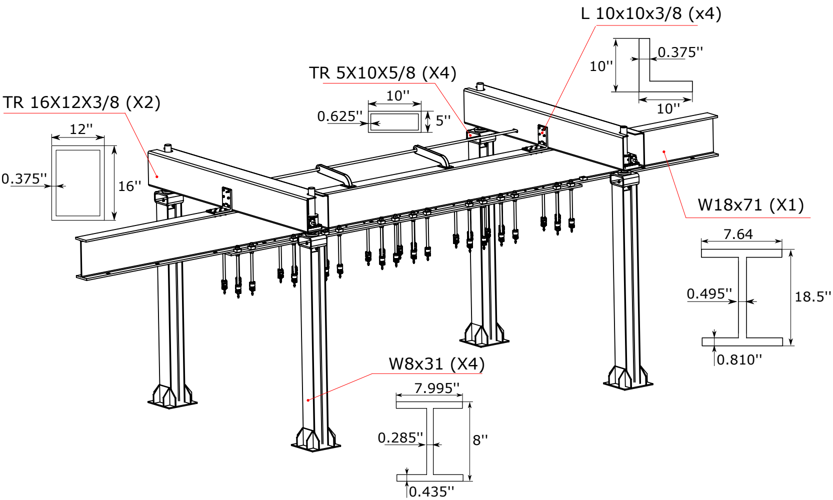
- Design for stiffness
- The Lifting beam is the critical component
  - An eccessive lifting beam deflection could cause undesidered effects
- The maximum displacement of the lifting beam can be estimated by using a classical beam theory
  - In this phase HB 650 string assembly load configuration was used (worst case)



$$f_b'' = F\frac{640a^3 + 1152a^2b + 384da^2 + 720ab^2 + 384dab + 169b^3 + 132db^2}{48EJ_{xx}}$$

Lifting tooling

Structure description



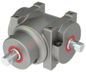
Lifting tooling

Lifting system

The Lifting system is composed by four worm screw jacks placed on each column and a mechanical transmission to syncronise the motion

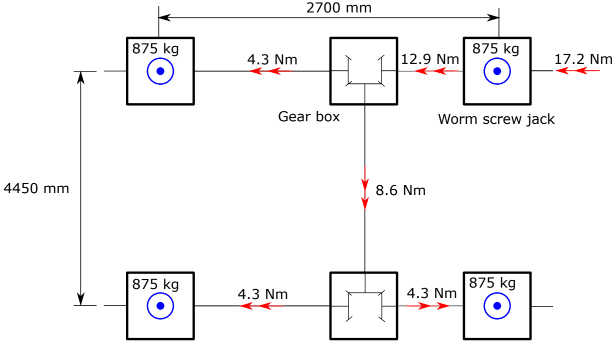
Capacity [kN]	Gear ratio	Torque to raise 1 kN [Nm]	Maximum input torque [Nm]
100	1:24	0.5	21.5

NOOK INDUSTRIES
Product code:
Actionjac EM10

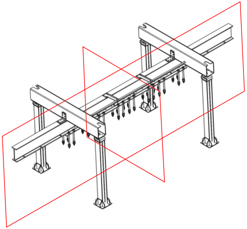


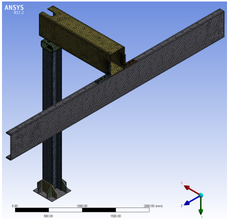
Gear ratio	Maximum input torque [Nm]
1:1	32

NOOK INDUSTRIES
Product code:
GB120



The structure has been numerically simulated by FEM software:Ansys Workbench®





- A quarter structure modeled
  - Taking advantage of double symmetry

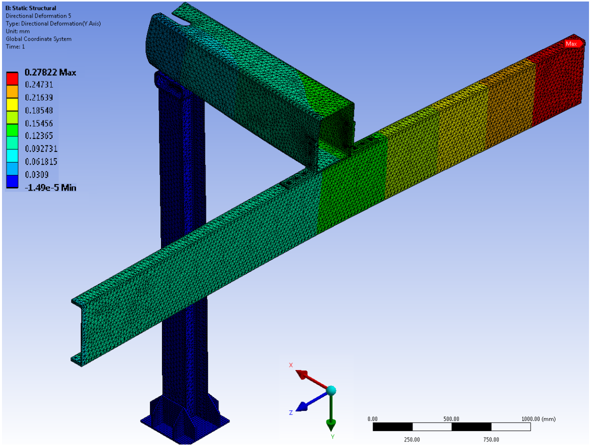
- Bonded contact

- HB 650 string load configuration

Lifting tooling

Numerical simulation: Results

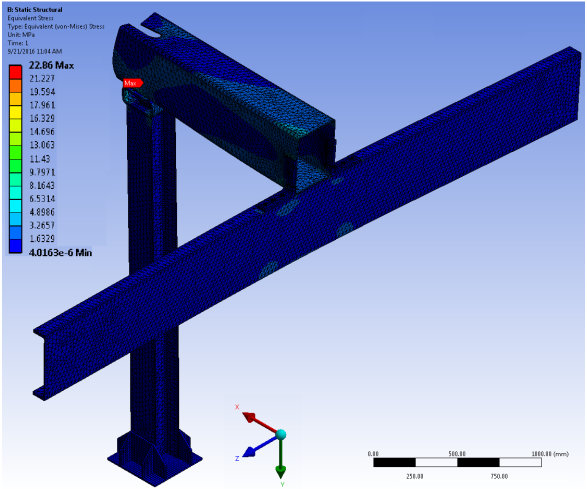
Displacement along y axis



Maximum displacement

0.28<1 mm

Von Mises Stress

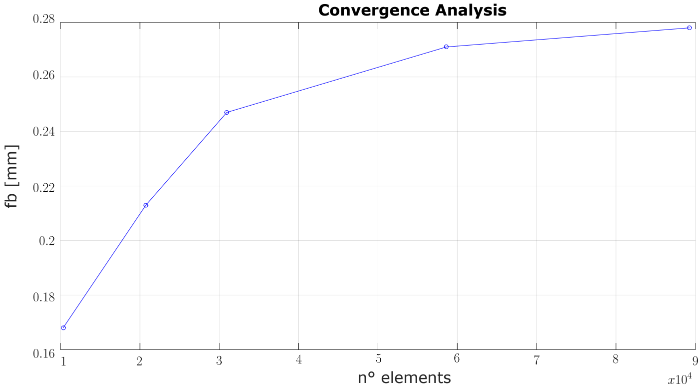


Maximum Stress
23 MPa

Lifting tooling

Numerical simulation: Convergence

Analysis	n° elements	CPU time [s]	f_b
1	20750	9.4	0.195
2	30951	16	0.247
3	40492	20	0.267
4	89247	38	0.278



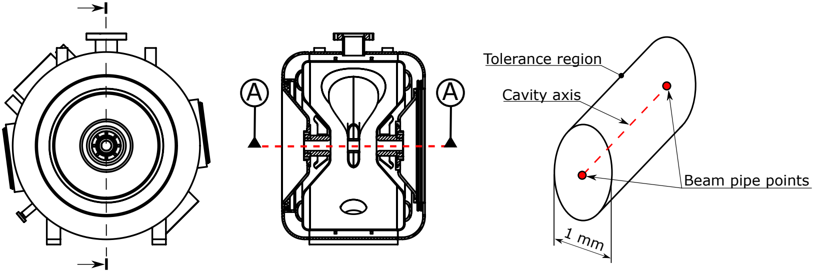
Assembling procedure SSR1 coldmass

String Alignment

Step 4

It is necessary to have the axis of the cavity geometrically aligned with beam axis within a tight range of tolerance

- In the case of SSR1 cavity the maximum error allowed is 1 mm
- The SSR1 cavities will be aligned according to the geometric axis (Axis A) with the help of the laser tracking technology

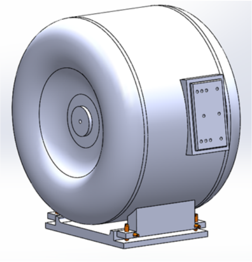


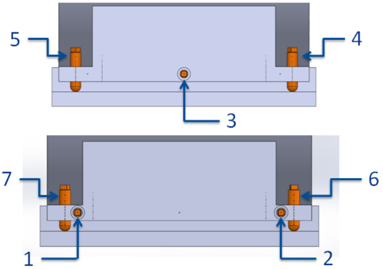
Alignment System

Description

The alignment is achieved through a total of seven screws

- The screws are designed to reduce the friction
- The tip of each screw is in contact with a reference surface
- It is possible to control each degree of freedom of the cavity by adjusting the screws





Mathematical model

Introduction

- The cavity can be considered as a rigid body
- The axis of instantaneous rotation is defined each time by the contact points of the screws which are not moving
- An idealized joint is chosen in order to develop a mathematical model even if the Screw-Surface interaction is not predictable

↓

The alignment process can be modeled as a multi-link serial robot

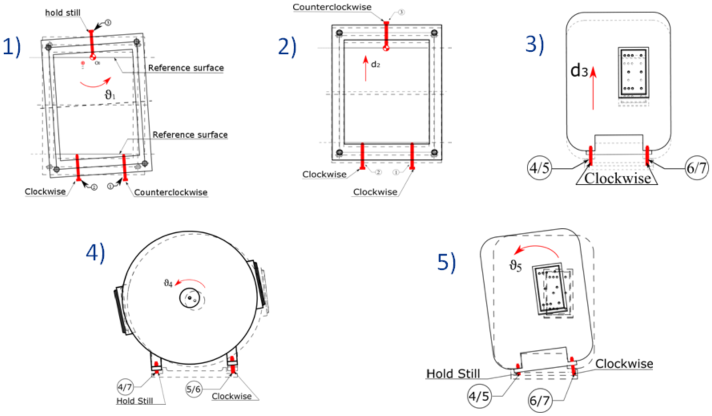
↓

In a serial robot the End-Effector configuration does not depend on the joint variable variation sequence, whereas in the rigid body case it does

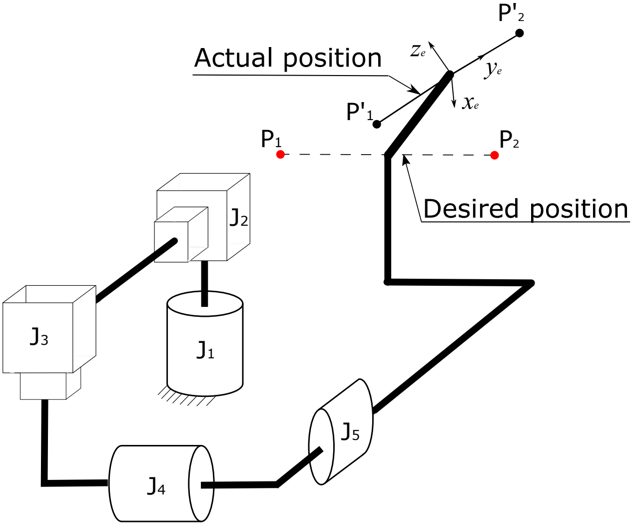
Mathematical model

Kinematic chain description

- The kinematic chain consists in three revolute joints and two prismatic joints
- The cavity has been assumed as the End-Effector



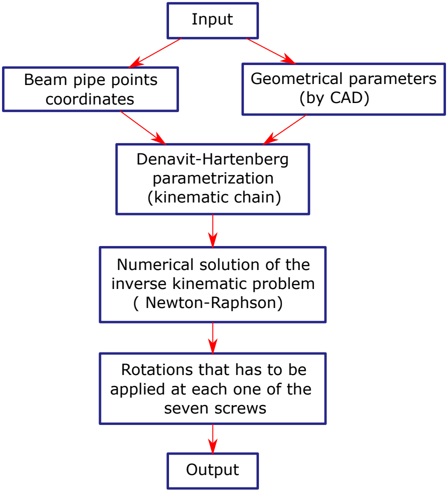
Complete kinematic chain



Mathematical model

Numerical implementation

The model has been implemented using Mathcad®



Test assembly SSR1 cavity

Necessary components

Strongback

Support posts

SSR1 cavity

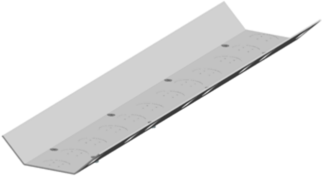
Alignment screws

Support plate

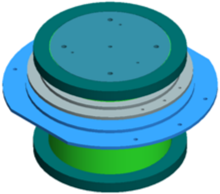
Test assembly SSR1 cavity

Necessary components

CAD models

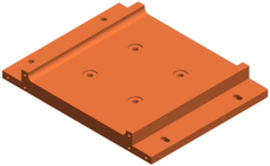


Strong-back

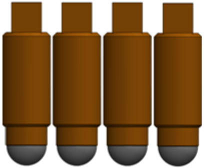


Support posts

SSR1 cavity



Support plate

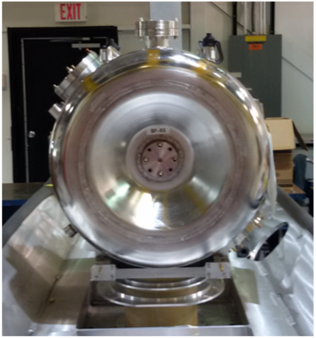


Alignment screws

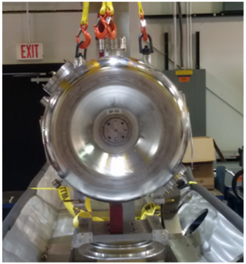
Test assembly SSR1 cavity

Assembling

Strong back lifting



Assemby completed



Transportation of the cavity (Overhead crane)

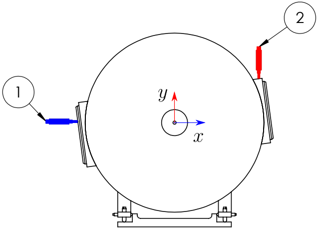
- Measurements were achieved using an analog gauge
- It was possible to measure only the displacement in a specific direction
- It is necessary to find a method to compare the measurements with the numerical code output

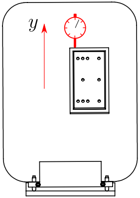
Graduations	Total Range	Range one Rev.	Stem Diameter
.0001″	.020″	.008″	.375″

Test measurements

Setup

- A direct measurement of the beam pipes position is not possible
- The gauges were placed on two plane surfaces of the cavity (Tuner plates) which are related to the axis of the cavity (CMM)
- The displacement of two points of the cavity in two orthogonal direction was measured
- The initial position of the gauges with respect to the cavity was obtained by caliper measurements





Test measurements

Setup

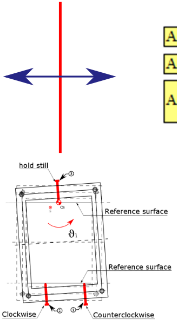
Test measurements
Results

Test 1

- 360° counterclockwise rotation screw 1
- 360° clockwise rotation screw 2
- Screw 3 fixed

Measurements

	Δ_2 [mm]	Average value [mm]
1	0.781	0.784
2	0.785	
3	0.778	
4	0.789	
5	0.786	



Mathcad code output

$AS1 = 366$ deg

$AS2 = -367$ deg

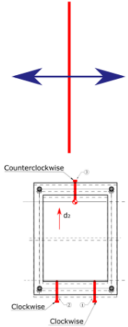
$AS3 := \frac{-d2 \cdot mm \cdot 360 \cdot deg}{P2} = 0$ deg

Test 2

- 360° clockwise rotation screw 1
- 360° clockwise rotation screw 2
- 360° counterclockwise rotation screw 3

Measurements

	Δ_1 [mm]	Average value [mm]
1	1.046	1.048
2	1.042	
3	1.055	
4	1.044	
5	1.052	



Mathcad code output

$AS1 = -361$ deg

$AS2 = -361$ deg

$AS3 := \frac{-d2 \cdot mm \cdot 360}{P2} = 361$ deg

Test measurements

Results

Test 3

- 360° clockwise rotation screw 4
- 360° clockwise rotation screw 5
- 720° clockwise rotation screw 6
- 720° clockwise rotation screw 7

Measurements

	Δ_1 [mm]	Average value [mm]
1	1.975	1.981
2	1.983	
3	1.979	
4	1.985	
5	1.982	

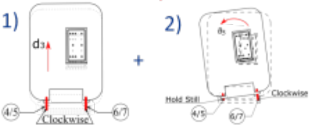
Mathcad code output

$$AS4 := \frac{d3 \cdot mm \cdot 360}{P1} = -354.6 \quad deg$$

$$AS5 := \frac{(ar1 + d3 \cdot mm) \cdot 360}{P1} = -354.6 \quad deg$$

$$AS6 := \frac{(ar1 + d3 \cdot mm + ar2) \cdot 360}{P1} = -719.4 \quad deg$$

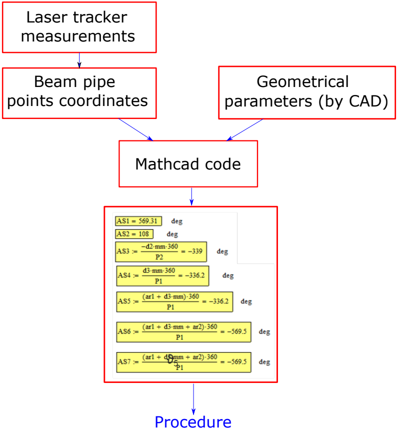
$$AS7 := \frac{(ar1 + d3 \cdot mm + ar2) \cdot 360}{P1} = -719.4 \quad deg$$



Conclusions

- It is possible to align the cavity with the screws system
- Process repeatability has been verified (five measurements for each case)
- Mathematical model has been successfully validated
- It would be necessary the use of laser tracking technology in order to have a precise alignment and remain within the tolerance constrain requirement

- This process must be performed in order to use the numerical code



1) Rotation ϑ_1 , Turning the screws 1,2
2) Translation d_2 , Turning the screws 1,2,3
3) Translation d_3, Turning the screws 4,5,6,7
4) Rotation ϑ_5 , Turning the screws 6,7