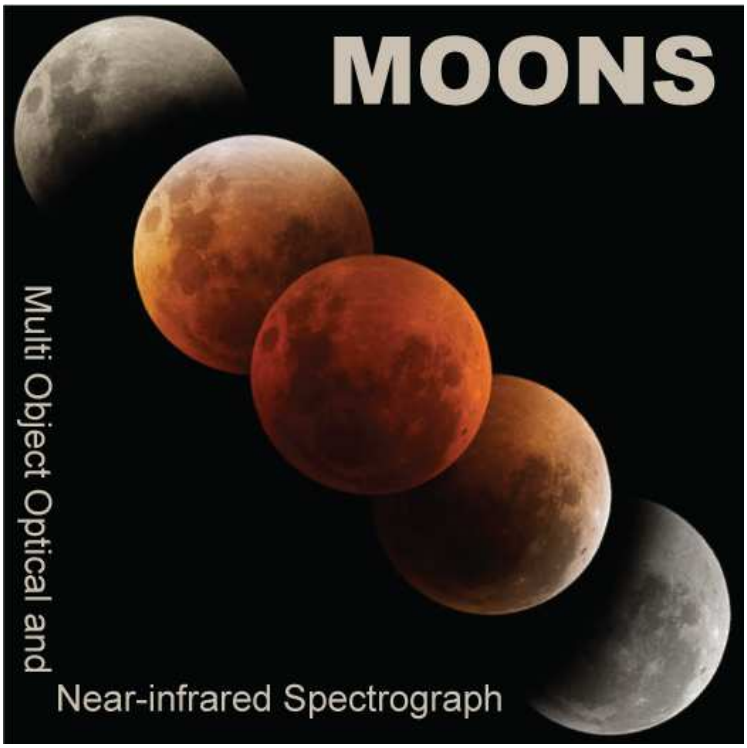

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1 INTRODUCTION

1.1 Purpose

This document describes test cases for the MOONS Fibre Positioner Software. It supplements the test cases described in the *MOONS Instrument Software Acceptance Test Plan,* [AD07]. The document also provides some test results for a prototype version of the software.

There are two classes of test case:

A. Test cases which deliberately cause a conflict between fibre positioners and check the ability of the software to detect and reject these situations.
B. Test cases which do not cause a conflict between fibre positioners but are difficult to achieve.

The document contains both kinds of test cases. In a lot of the cases, variants A and B are based on the same test, with B moving the fibre positioners slightly apart until they long longer conflict.

1.2 Applicable Documents

The following documents of the exact issue shown form part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this document shall be considered a superseding requirement.

Table 1-1: Applicable Documents

Ref No	Document/Drawing Number	Document Title	Issue No
AD01	VLT-SPE-MON-14620-3001	MOONS Instrument Software User Requirements	1.4
AD02	VLT-SPE-MON-14620-3002	MOONS Instrument Software Functional Specification	2.0
AD03	VLT-TRE-MON-14620-3007	MOONS Rotating Front-End Software Design Description	1.0
AD04	VLT-TRE-MON-14620-3009	MOONS Shared Library Software Design Description	1.0
AD05	VLT-SPE-MON-14620-4303	MOONS RFE to Instrument Software Interface Control Document	1.5
AD06	VLT-ICD-MON-14620-4311	MOONS RFE Electronics Interface Description	1.0
AD07	VLT-PLA-MON-14620-3005	MOONS Instrument Software Acceptance Test Plan	1.0

1.3 Reference Documents

The following documents are referenced by this document.

Table 1-2 Referenced Documents

Ref No	Document/Drawing Number	Document Title	Issue No
RD01	STFA 001-4 01.02 ???	Will Cochran, 9/8/2016, BETA ARM Collision Zones (sheets 1-10)	1.0
RD02			

1.4 Overview

The MOONS fibre positioner obeys the requirements described in [AD01] and its software design is described in [AD02] and [AD03]. Each fibre positioner can reach a target within its patrol zone, and the patrol zone of each fibre positioner can overlap with up to 18 of its neighbours. The left hand side of Figure 1 shows a configuration of 19 positioners; where the central positioner (labelled 1) could interact with any of the other positioners. Each fibre positioner can reach a target in a left-armed or right-armed configuration (defined by a parity setting).

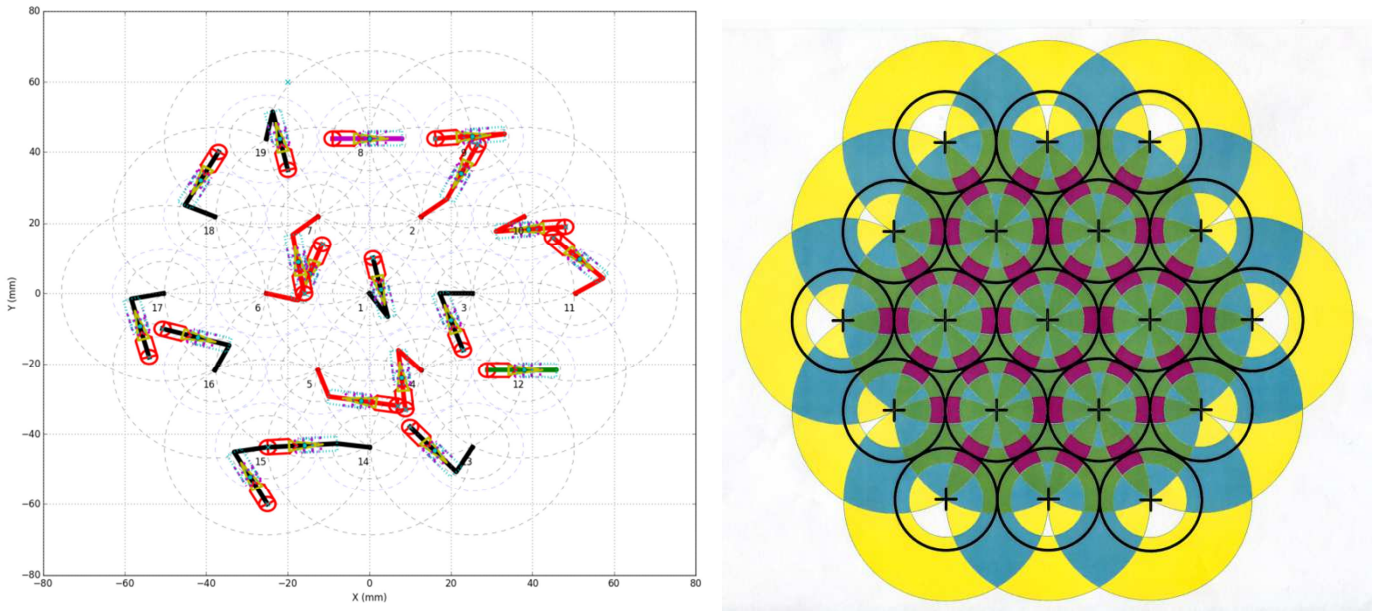


Figure 1: Fibre Positioner Layout and Sky Coverage

The right hand side of Figure 1 shows the sky coverage of the fibre positioners, showing the zones where 2 (cyan), 3 (green) or 4 (magenta) fibre positioners can be brought together to pick off close targets. At the locations marked "+" it is theoretically possible to bring 6 positioners together. The most difficult target acquisition scenarios are the ones where close targets are picked off by neighbouring positioners. A collection of difficult scenarios are described in this document to make 2-positioner, 3-positioner, 4-positioner and 6-positioner test cases. These test cases can be used to test the limitations of fibre positioner software and to test the control of the fibre positioner cluster prototype.

1.5 Requirements

The fibre positioner system must fulfil the following requirements, as defined in [AD01]. Each requirement will be verified during acceptance testing either by analysis of the design, by inspection of the delivered code, by a demonstration or by an explicit test. This document only describes explicit tests.

Label	Description	Verification
REQ 3.1-02	Information on the as-manufactured location and orientation of the fibre positioners on the focal plane, and the fields of view and location of the acquisition cameras on the focal plane, will be provided in the MOONS instrument package.	By inspection
REQ 3.1-03	Each software subsystem is responsible for converting between MOONS focal plane coordinates and the local coordinate system of the component controlled by that software.	By design
REQ 3.1-07	The MOONS top-level software shall also provide functions, which correct MOONS focal plane coordinates for thermal expansion.	By design and by positional accuracy test
REQ 3.1-08	The local reference point for each fibre positioner shall be the place where the axis of the alpha motor intersects with the MOONS focal plane.	By design
REQ 3.1-09	The MOONS fibre positioner software shall account for any significant measured angle of tilt between the "as manufactured" patrol field of a fibre positioner and the tangent plane.	By design and by positional accuracy test
REQ 3.1-10	The X axis of the local coordinate system of a MOONS fibre positioner unit is defined as the direction of the alpha arm at its zero point.	By design
REQ 3.1-11	The MOONS fibre positioner software shall take into account any "as manufactured" yaw between the local X axis and the MOONS focal plane Y axis.	By design and by positional accuracy test
REQ 3.4-04	An exclusion zone shall be defined around each metrology fiducial marker to ensure that none of the metrology cameras are prevented from seeing the fiducial marker by fibre positioners blocking the line of sight.	By design and by demonstration
REQ 3.4-06	The MOONS software must also take into account the fact that an observation might be aborted, extended or repeated by the operator.	By design and by test.

REQ 3.4-07	Each MOONS fibre positioner unit shall have a default location, which shall be close enough to allow the fibre positioners to be moved to datum without collision avoidance planning.	By design and by demonstration
REQ 3.5-01	Before making an observation, the MOONS fibre positioner software shall check that all the fibre positioners (with the exception of known broken units) are at their expected locations.	By design and by demonstration
REQ 3.5-03	Fibre positioner paths must be reversible.	By design and by test
REQ 3.5-04	The MOONS fibre positioner software must also be capable of replanning the fibre positioner paths at the telescope; making adjustments for atmospheric dispersion corrections, thermal expansion corrections, and correcting for broken fibre positioners.	By design and by test
REQ 3.5-05	The MOONS fibre positioner software shall keep a record of the history of the motion of the fibre positioners for troubleshooting purposes. The record must store the movements at least back to the last SETUP command	By demonstration
REQ 3.6-01	The MOONS instrument software shall implement the standard states required by the ESO/VLT software, namely: OFF, LOADED, STANDBY, ONLINE.	By design.
REQ 3.6-02	The MOONS software shall implement an additional state model, which prevents the fibre positioner executing a SETUP command, or moving to the datum switches, until the configuration of the positioner arms is known.	By design
REQ 3.7-01	Changes in the status of the MOONS instrument shall be communicated to the Observation Preparation Software using an Instrument Configuration file, which must be updated at regular intervals.	By design
REQ 3.7-02	Whenever a change to the Instrument Configuration is attempted, the software shall ask for confirmation before validating the change.	By demonstration
REQ 3.8-01	During assembly integration and testing, missing components of the instrument shall be simulated.	By design and by demonstration
REQ 3.9.6-01	The MOONS software shall log unrecoverable errors, changes in instrument status and state, acquisition images, guide star signal to noise measurements, telescope pointings, time taken to configure the fibre positioner, fraction of fibre positioners reaching their targets, temperatures, warnings and alarms.	By demonstration
REQ 3.13-01	Interlocks shall be used to prevent aggravation of a hazardous condition after a power failure.	By design and by demonstration
REQ 3.13-02	The fibre positioner system shall retain the last known location of each positioner in non-volatile storage to guard against unexpected power failures.	By design and by demonstration
REQ 3.14-03	Parameter values shall be checked for validity. An error shall be returned whenever a parameter value is not valid (unknown name or numerical value outside valid range).	By demonstration
REQ 3.14-04	Devices shall be configured in parallel where possible to increase the setup efficiency. Devices which do not depend on the telescope pointing shall be configured in parallel with the telescope slew where possible	By demonstration
REQ 3.18-01	The initialization of the whole instrument shall not take longer than 6 minutes, in the worst case when the fibre positioner configuration is unknown, or less than 1 minute from a known configuration.	By demonstration
REQ 3.18-02	The setup of the whole instrument before any exposure shall not take longer than 30 seconds	By demonstration
REQ 3.19-02	Instrument tests shall include a self-test of all instrument mechanisms and a communications check between critical components.	By demonstration
REQ 3.20-01	A collision prevention and detection mechanism shall be used to protect the fibre positioners.	By tests in simulation mode and by demonstration

REQ 3.20-02	The MOONS software shall not be solely responsible for the safety of personnel or instrument hardware. Serious alarm conditions, which may leave the instrument in a hazardous condition, shall be avoided by appropriate hardware design. The MOONS software shall inform the operator of interlock conditions.	By demonstration

Conflicts between fibre positioners (**REQ 3.5-04** and **REQ 3.20-01**) are prevented by two software packages, described in [AD04]:

- The conflict checker package checks that when fibre positioners acquire a set of targets, with given parity settings, there is no conflict in the final configuration. Fibre positioners shown in red in Figure 1 are in conflict because they are trying to occupy the same space.

  The conflict checking software must detect and successfully reject all the target and parity combinations which result in a collision between hardware components. The collision avoidance zones used by the conflict checker must be sufficiently well sized and placed to prevent all possible collision scenarios.

- The path analysis software plots a safe path so that each fibre positioner can move from its default location to its target without colliding with neighbouring positioners.

  The path analysis software must prevent the fibre positioners from colliding while travelling between one configuration and the next. The final outcome must either be success or deadlock, never a collision. Although the path analysis software can assume that the conflict checking software will have filtered out targets that conflict, it cannot assume the high-level software will have chosen sensible parity combinations. If a target/parity combination does not conflict, the path analysis software must be able to attempt it, with the end result being either success or deadlock. *The ratio of success to deadlock must be high enough for MOONS to acquire the targets needed to reach its science goals*.

The fibre positioner software must always check a set of targets with the conflict checking software before passing those targets to the path analysis software.

Since the conflict checker and path analysis are fulfilling different roles, two different variations of each scenario are analysed:

A. Target coordinates which result in a conflict between the fibre positioners. The conflict checking software must detect a conflict between the fibre positioners.

B. A variation of A where one of the targets is moved away from the other target until the conflict checker software reports that the fibre positioners are no longer in conflict. Variation B represents a very difficult but feasible scenario for the path analysis software. The path analysis software must not cause a collision while attempting these scenarios, but it should also be capable of reaching some of these final configurations without deadlock.

2 Two Positioner Test Cases

Most of the following test cases are based on the collision scenarios described in Will Cochran's drawing set entitled "Collision Zones", [RD01], which consists of 13 sheets. The test cases have been reordered so that tests involving the same avoidance zones are grouped together. The translation between sheet number and test case number is as follows:

Sheet number in [RD01]	Test Case Number
1	2
2	1
3	3
4	9
5	4
6	5
7	7
8	10
9	6
10	11
11	8

Test cases 8, 12 and 13 are extra scenarios for testing the conflict check software and test cases 14 and 15 are extra scenarios for testing the path analysis software.

2.1 Fibre Positioner Configuration

These two positioner test cases use fibre positioners whose centres are located in MOONS focal plane coordinates as defined in the following table.

Table 2-1: Two Positioner Configuration

Fibre positioner	POS RFOCAL (mm)	POS THFOCAL (deg)	POS ORIENT (deg)	POS YFOCAL (mm)	POS ZFOCAL (mm)
1	43.74780	180.0000	0.0	0.000	-43.748
2	50.51471	210.0000	0.0	-25.257	-43.748

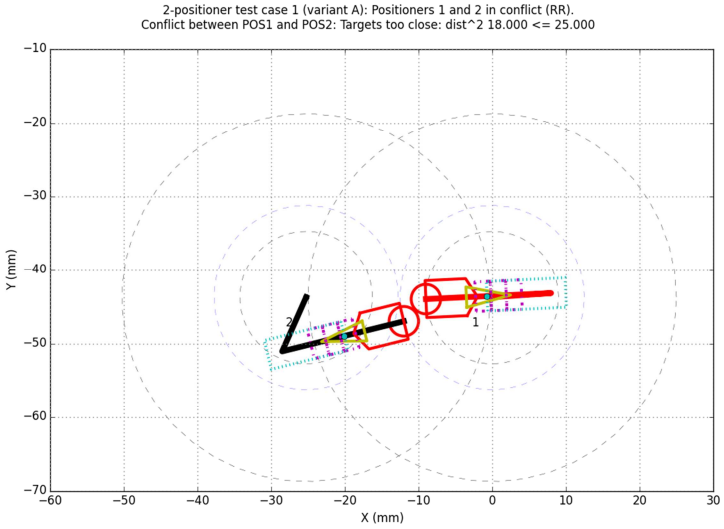
2.2 Fibre Holder to Fibre Holder Conflict

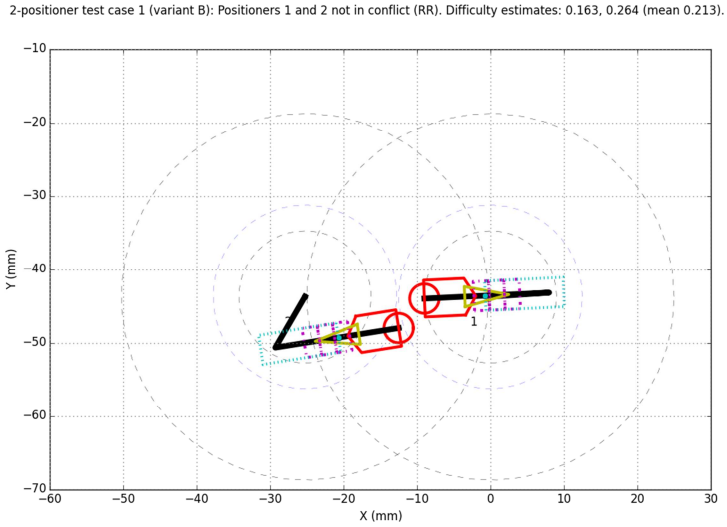
2.2.1 Test Case 1

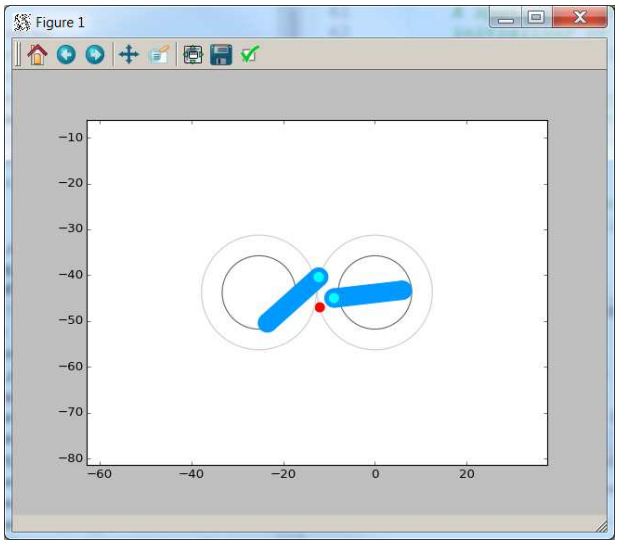
Table 2-2: Two Positioner Test Case 1 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	44.911	191.560	-9.00	-44.00
	B	"	"	"	"
2	A	38.053	183.013	-2.00	-38.00
	B	37.121	184.635	-3.00	-37.00

Scenario variation A is prevented by the conflict checking software (targets too close). The path analysis software deadlocks in both variations A and B. Positioner 2 attempts to reach its target in the wrong direction (clockwise) and meets positioner 1,







2.3 Metrology Target to Metrology Target Conflict

2.3.1 Test Case 2

In this test case the curved edges of the fibre positioner arms clash, as shown below. The metrology avoidance zone at the top of each beta arm was widened by ~1mm to prevent such a clash.

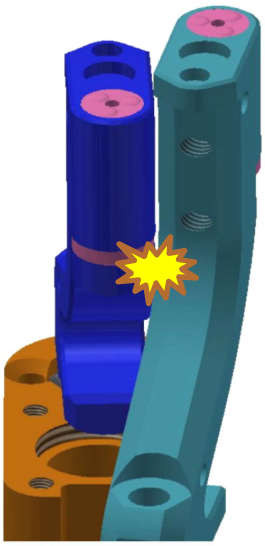
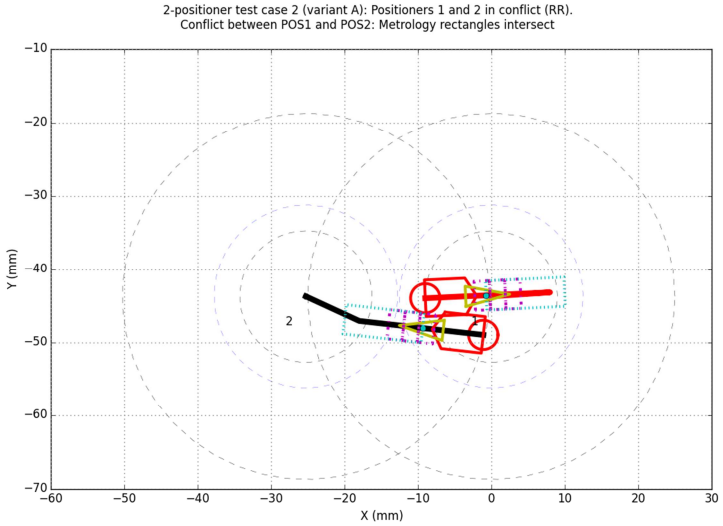
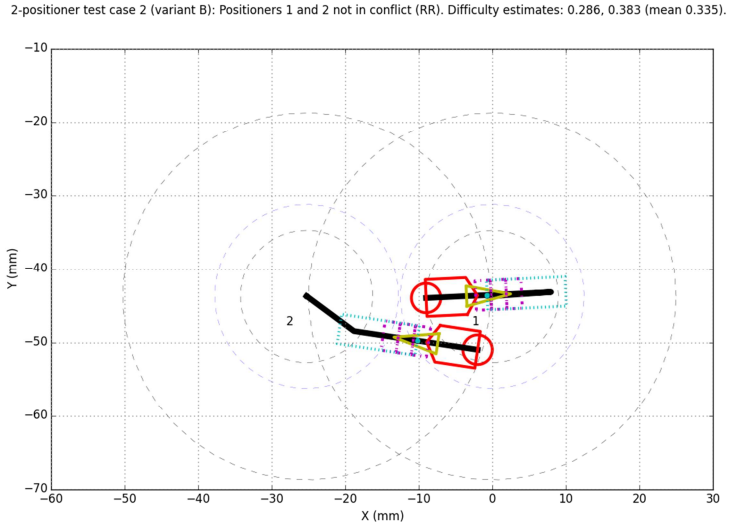


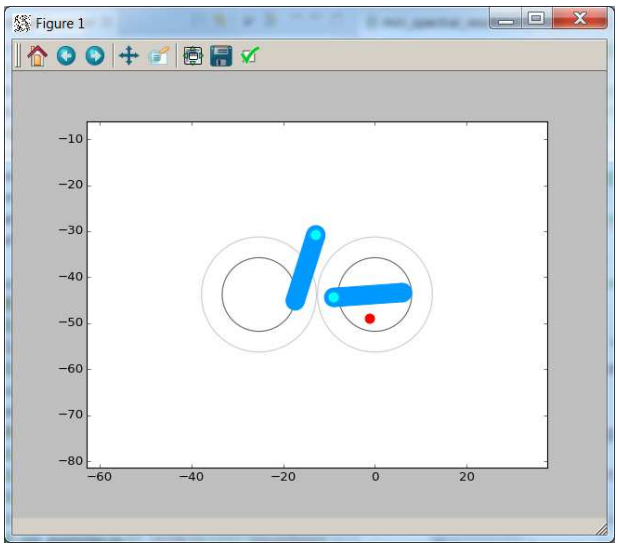
Table 2-3: Two Positioner Test Case 2 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	44.911	191.560	-9.00	-44.00
	B	"	"	"	"
2	A	49.012	181.286	-1.10	-49.00
	B	51.039	182.246	-2.00	-51.00

Scenario variant A is prevented by the conflict checking software (metrology zones intersect), with the metrology avoidance zone to be widened by ~1mm (TBC) to prevent a clash between the curved edges of the beta arms. The result of the conflict analysis software in each variation is shown on the left hand side of the diagram below. The path analysis software deadlocks in both variations A and B and ends up in the situation shown on the right hand side of the diagram below. Positioner 2 attempts to reach its target in the wrong direction (clockwise) and meets positioner 1.





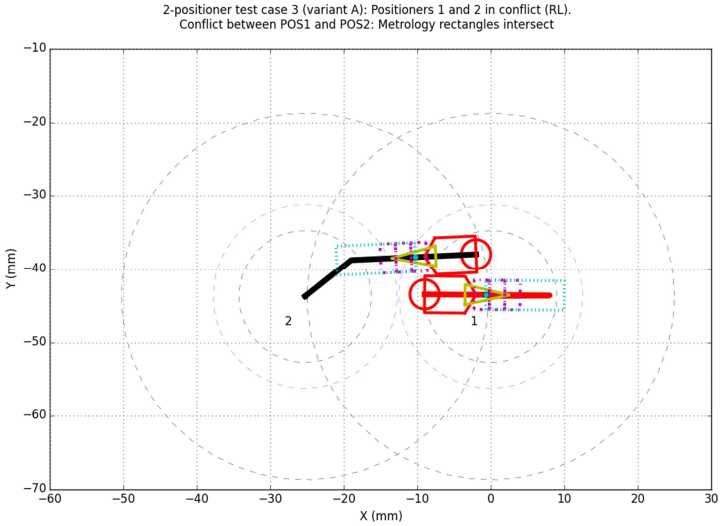


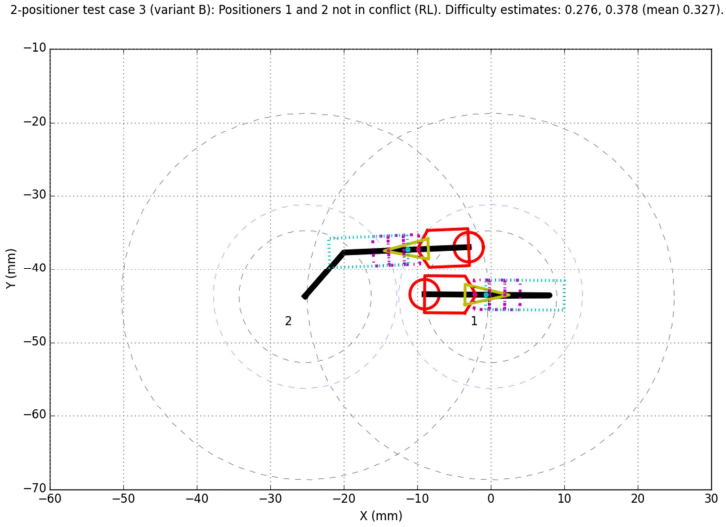
2.3.2 Test Case 3

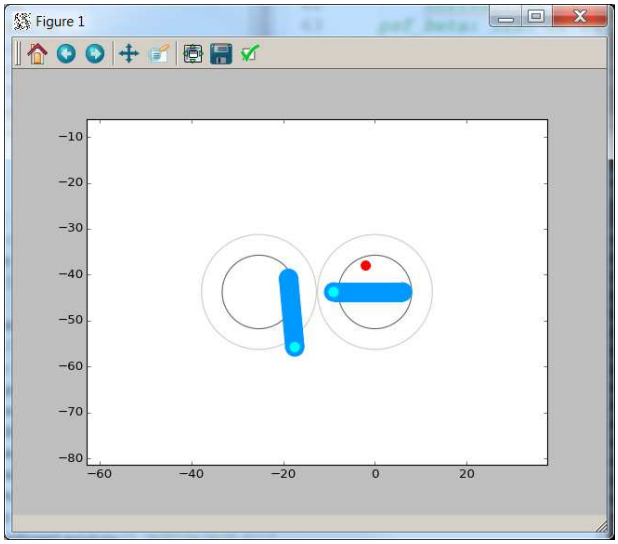
Table 2-4: Two Positioner Test Case 3 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	44.421	191.689	-9.00	-43.50
	B	"	"	"	"
2	A	38.053	183.013	-2.00	-38.00
	B	37.121	184.635	-3.00	-37.00

Scenario variation A is prevented by the conflict checking software (metrology zones intersect). The path analysis software deadlocks in both variations A and B. Positioner 2 attempts to reach its target in the wrong direction (anti-clockwise) and meets positioner 1.





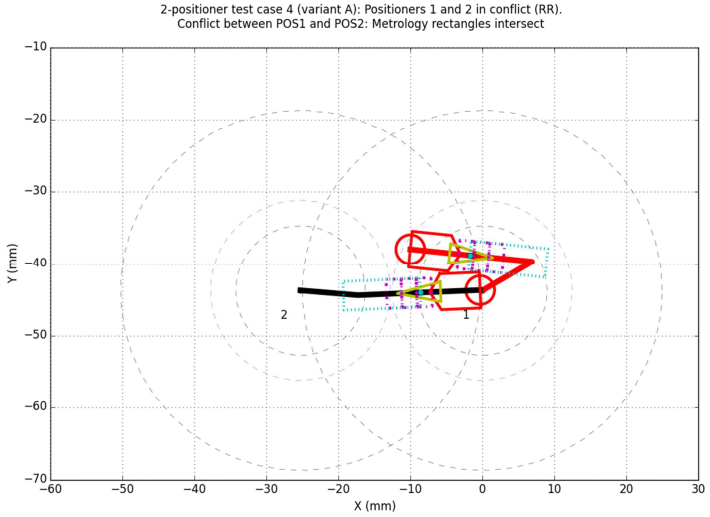


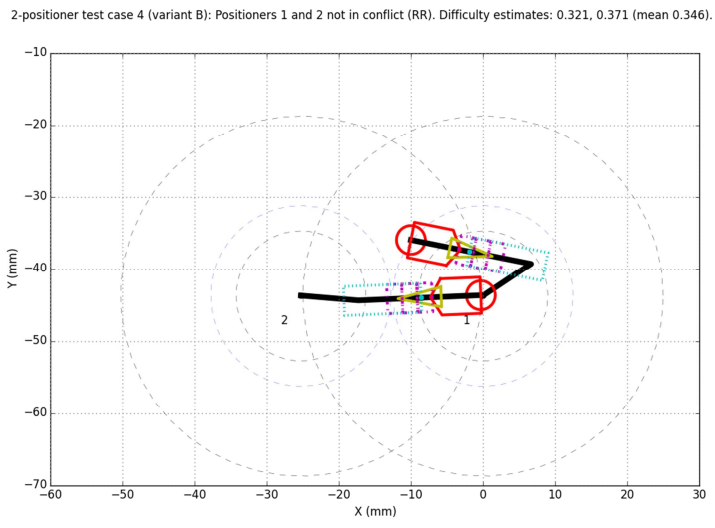
2.3.3 Test Case 4

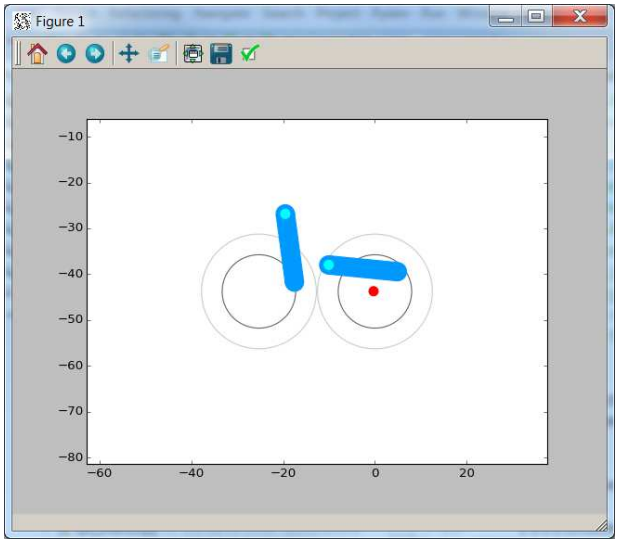
Table 2-5: Two Positioner Test Case 4 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	39.294	194.744	-10.00	-38.00
	B	37.363	195.524	-10.00	-36.00
2	A	43.701	180.393	-0.30	-43.70
	B	"	"	"	"

Scenario variation A is prevented by the conflict checking software (metrology zones intersect). The path analysis software deadlocks in both variations A and B. Positioner 2 attempts to reach its target in the wrong direction (clockwise) and meets positioner 1.





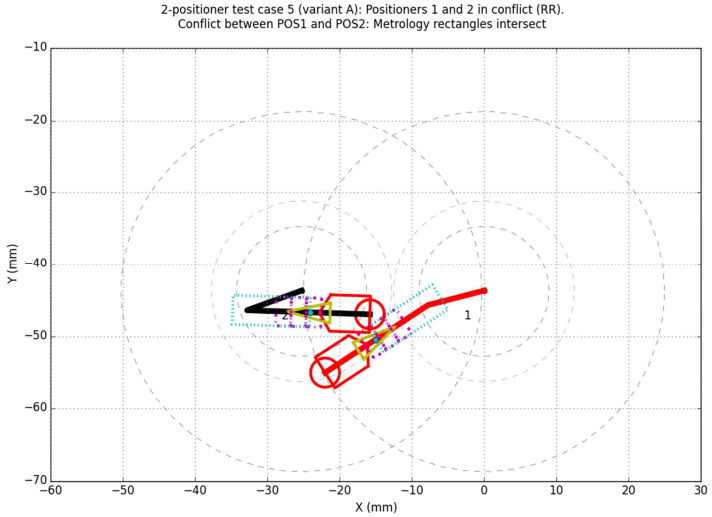


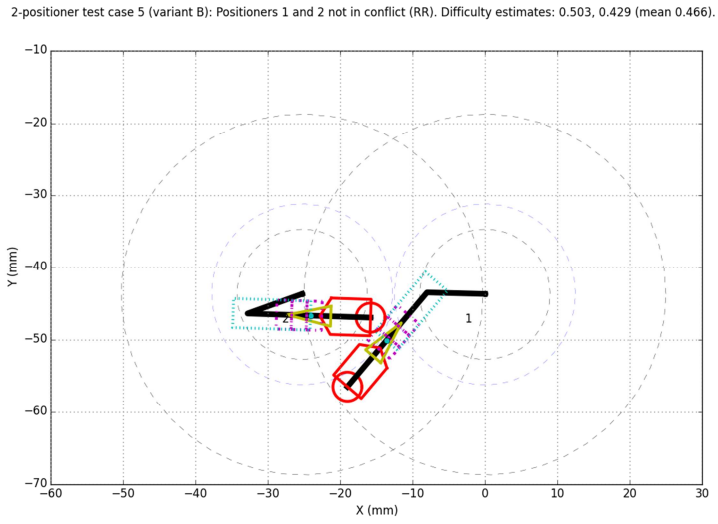
2.3.4 Test Case 5

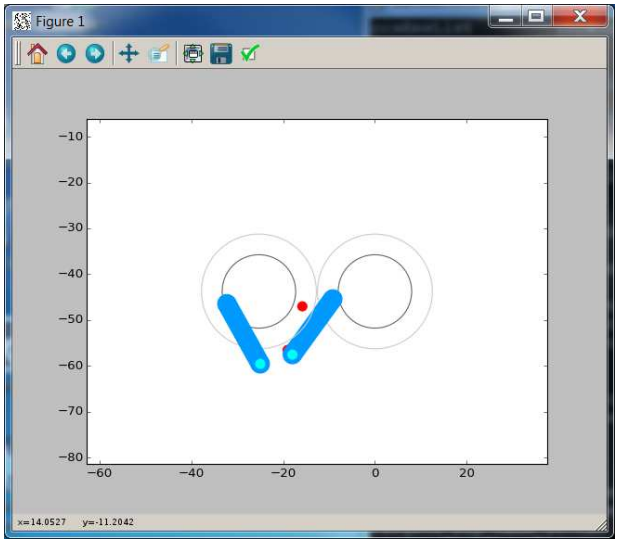
Table 2-6: Two Positioner Test Case 5 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	59.237	201.801	-22.00	-55.00
	B	59.609	198.587	-19.00	-56.50
2	A	49.585	198.581	-15.80	-47.00
	B	"	"	"	"

Scenario variation A is prevented by the conflict checking software (metrology zones intersect). The path analysis software deadlocks in both variations A and B. Positioner 2 attempts to reach its target in the wrong direction (anti-clockwise) and meets positioner 1





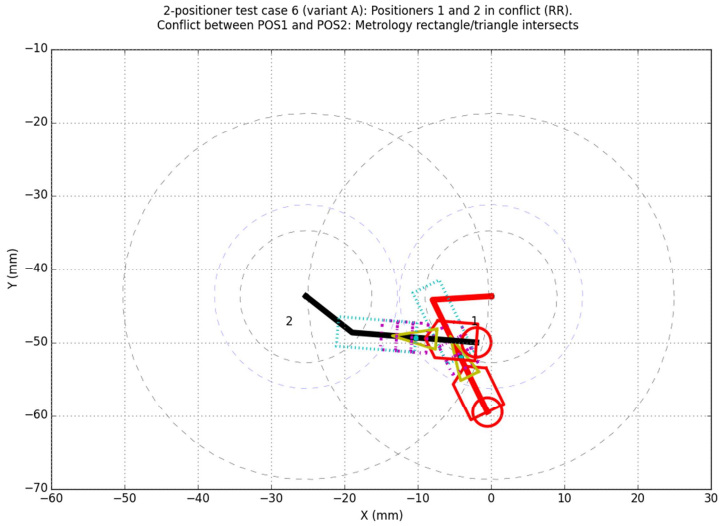


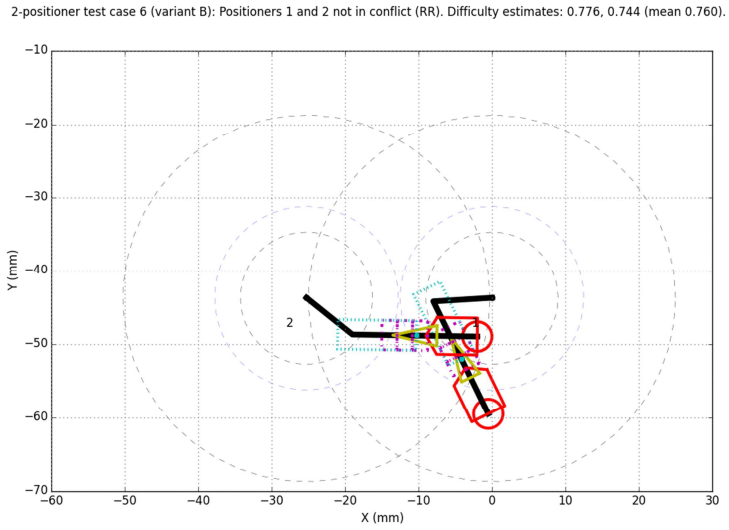
2.3.5 Test Case 6

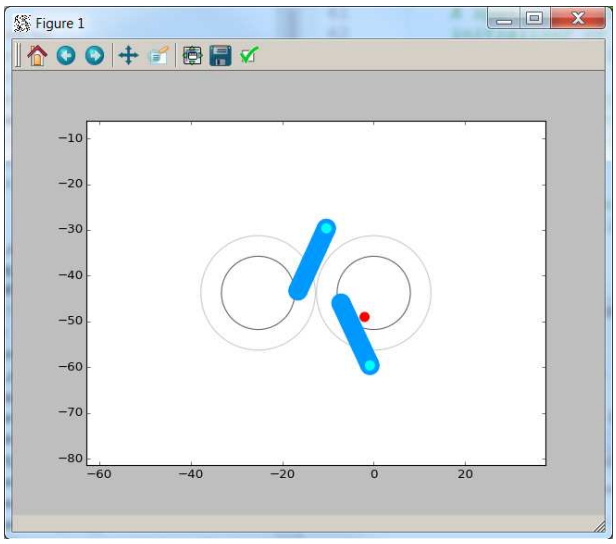
Table 2-7: Two Positioner Test Case 6 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	59.502	180.481	-0.50	-59.50
	B	"	"	"	"
2	A	50.040	182.291	-2.0	-50.0
	B	49.041	182.337	-2.0	-49.0

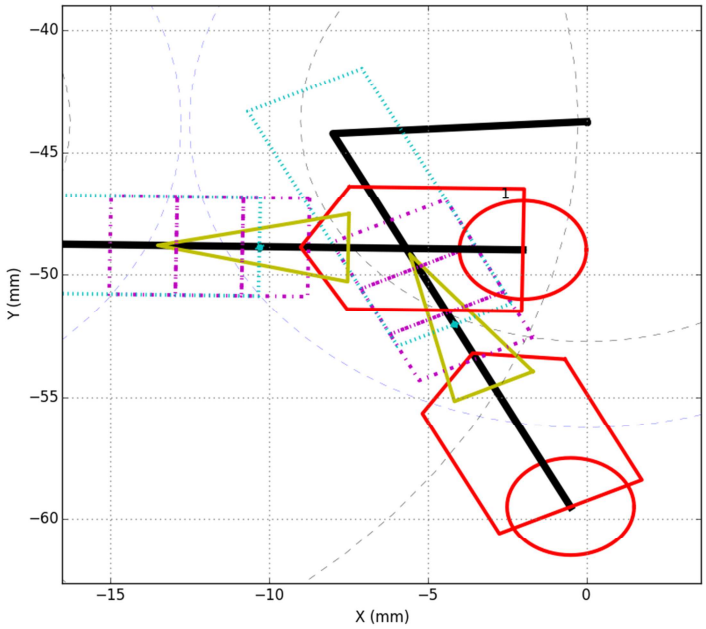
Scenario variation A is prevented by the conflict checking software (metrology zones intersect). Nothing is in conflict in the final configuration of variation B, but this is a very tight situation. The path analysis software deadlocks in both variations A and B. Is it possible for the fibre positioners to move to this or a similar tight configuration without deadlock?



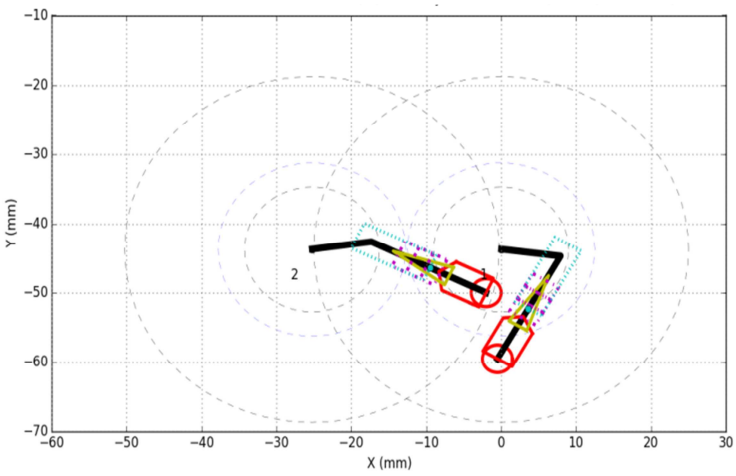


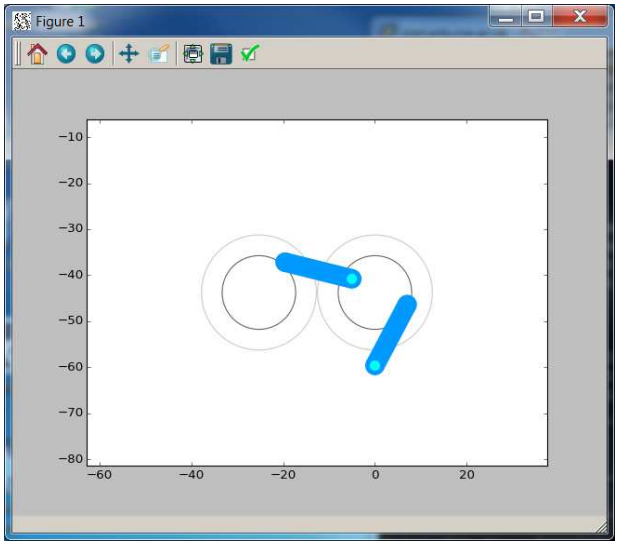


The figure below shows a close-up of the scenario variation B. Fibre 2 has been dragged over beta arm 1, the two metrology zones and datum actuators are both in close proximity but neither are overlapping. Do we have the necessary fine control in the path analysis software to steer a positioner into this narrow space without a collision?



Note that this difficult situation can be mitigated by a different choice of parity settings, as shown below. This configuration has a lower “degree of difficulty” estimate (0.289 compared with 0.760). Unfortunately, the path analysis software still deadlocks at these the new parity settings.





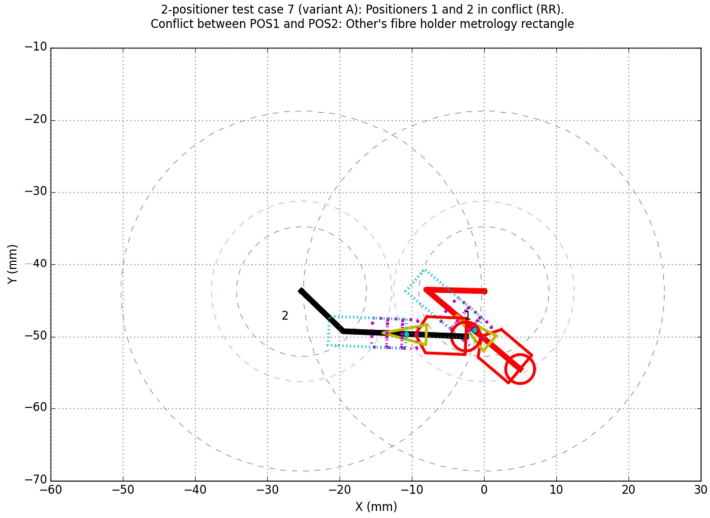
2.4 Fibre Holder to Metrology Target Conflict

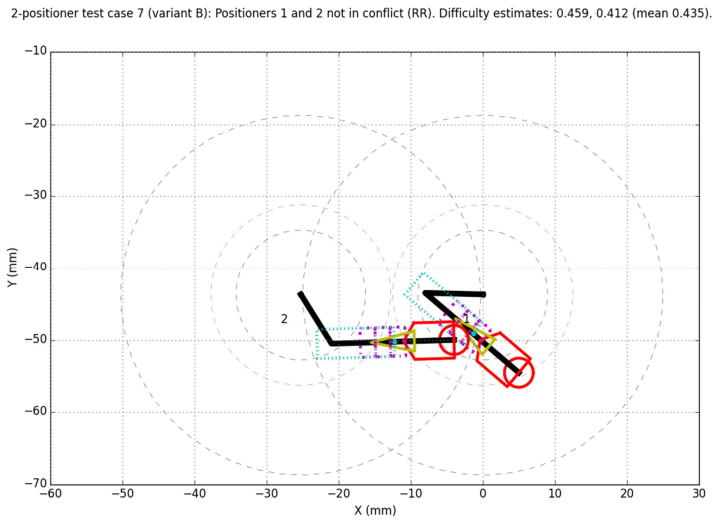
2.4.1 Test Case 7

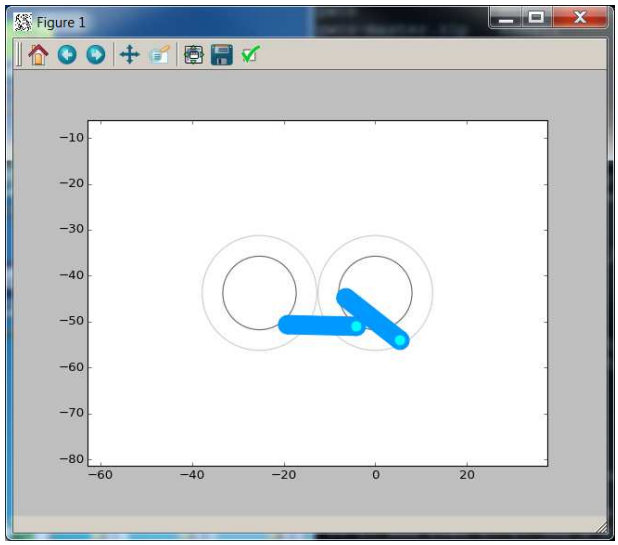
Table 2-8: Two Positioner Test Case 7 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	54.729	174.758	5.00	-54.50
	B	"	"	"	"
2	A	50.062	182.862	-2.50	-50.00
	B	50.160	184.574	-4.00	-50.00

Scenario variation A is prevented by the conflict checking software, but only because of the fibre snag triangle. What happens if the fibre snag zone is removed? The path analysis software deadlocks for variation A but succeeds for variation B.





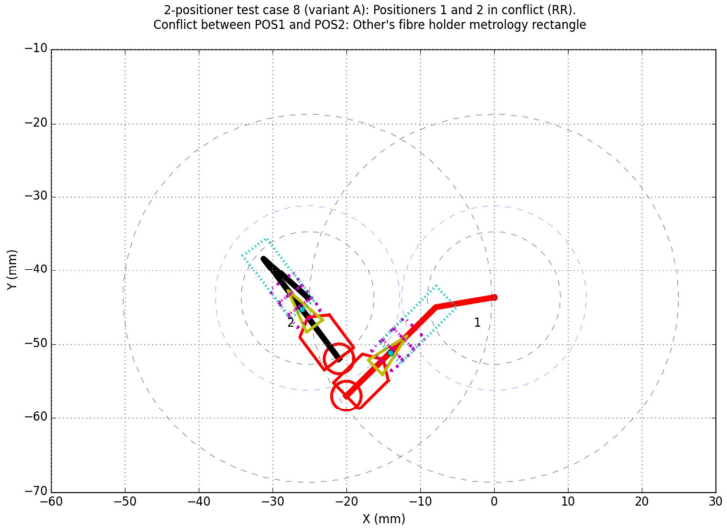


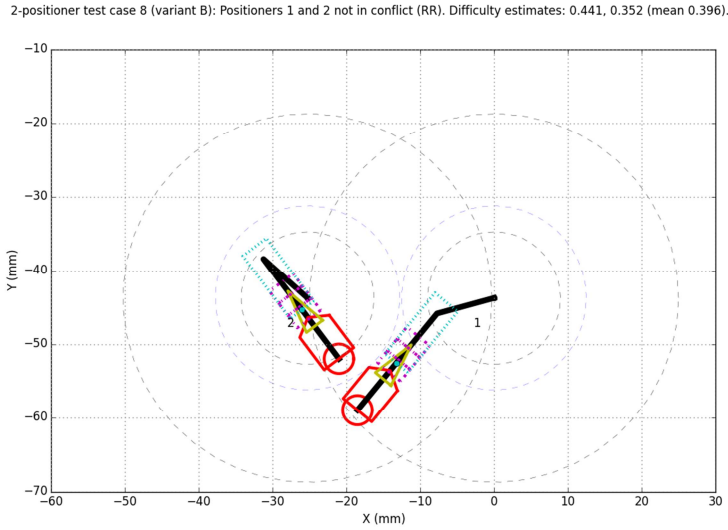
2.4.2 Test Case 8

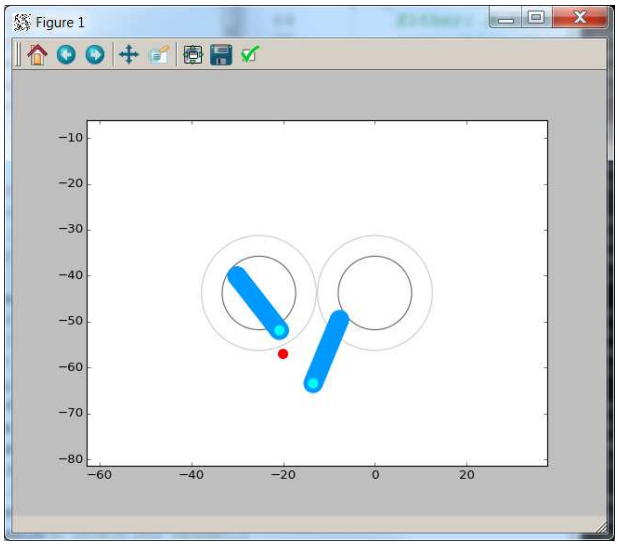
Table 2-9: Two Positioner Test Case 8 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	60.407	199.335	-20.00	-57.00
	B	61.832	197.409	-18.50	-59.00
2	A	56.080	201.991	-21.00	-52.00
	B	"	"	"	"

Scenario variation A is prevented by the conflict checking software (fibre holder and metrology zones intersect). The path analysis software deadlocks in both variations A and B.







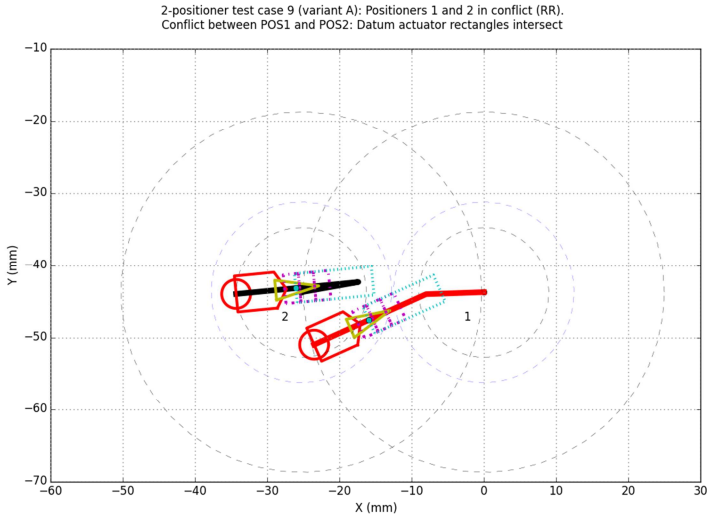
2.5 Datum Actuator to Datum Actuator

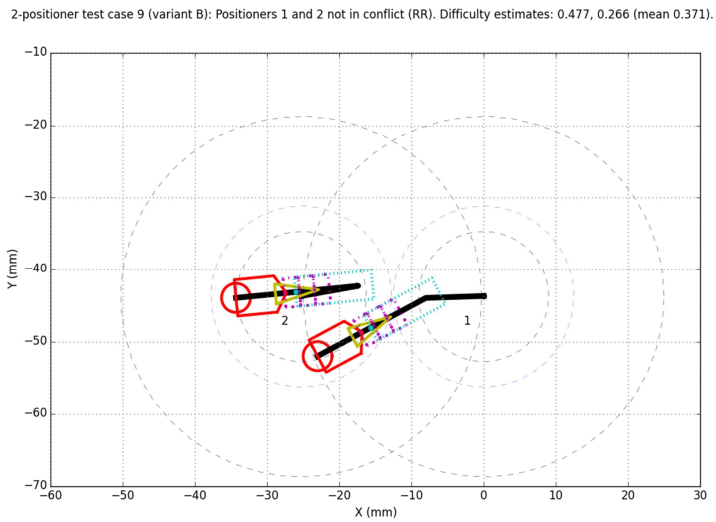
2.5.1 Test Case 9

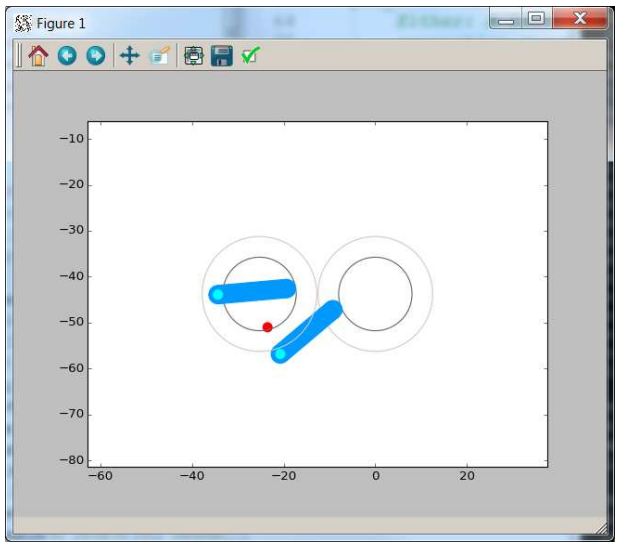
Table 2-10: Two Positioner Test Case 9 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	56.154	204.740	-23.50	-51.00
	B	56.859	203.860	-23.00	-52.00
2	A	55.790	217.938	-34.30	-44.00
	B	"	"	"	"

Scenario variation A is prevented by the conflict checking software (datum actuators intersect). The path analysis software deadlocks in both variations A and B.





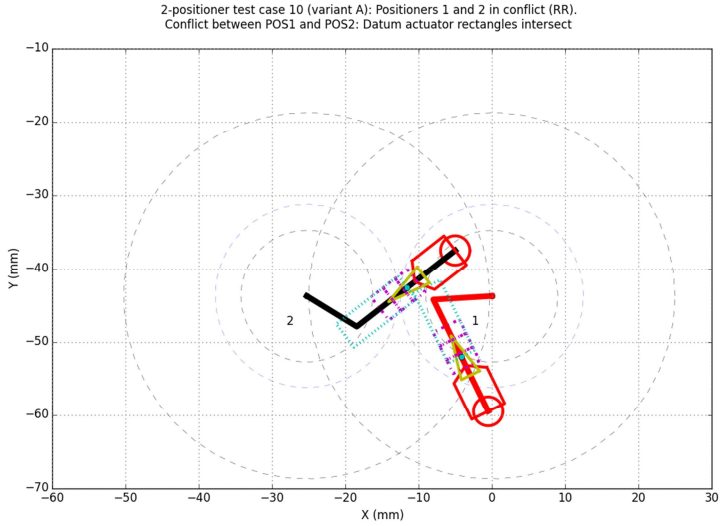


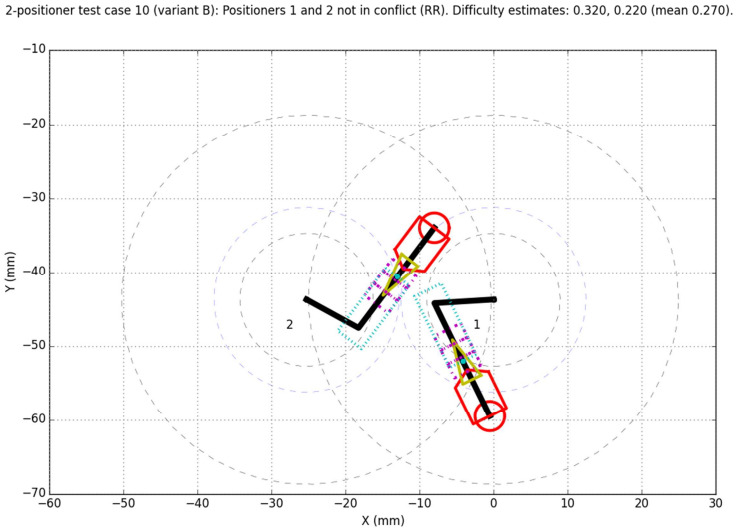
2.6 Test Case 10

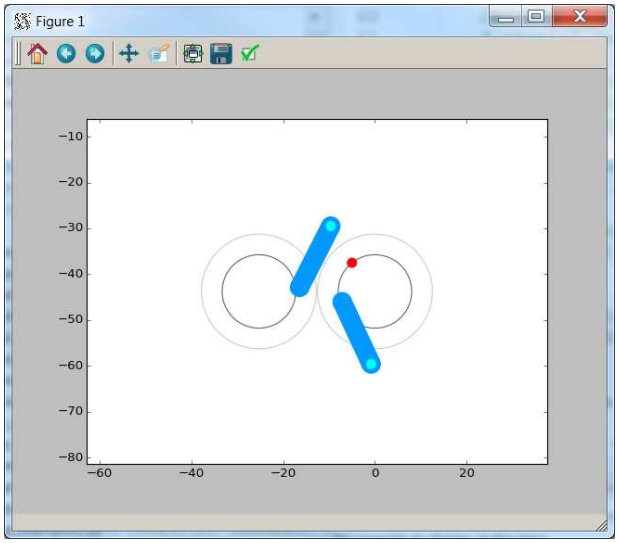
Table 2-11: Two Positioner Test Case 10 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	59.502	180.481	-0.50	-59.50
	B	"	"	"	"
2	A	37.832	187.595	-5.00	-37.50
	B	34.928	193.241	-8.00	-34.00

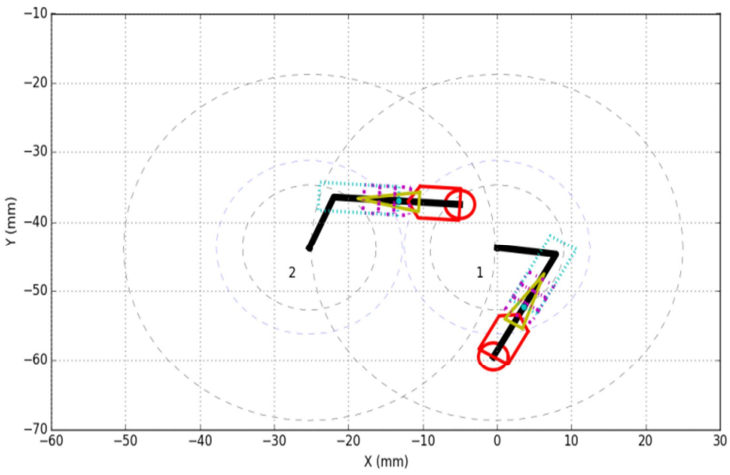
Scenario variation A is prevented by the conflict checking software (datum actuators intersect). The path analysis software deadlocks in both variations A and B.

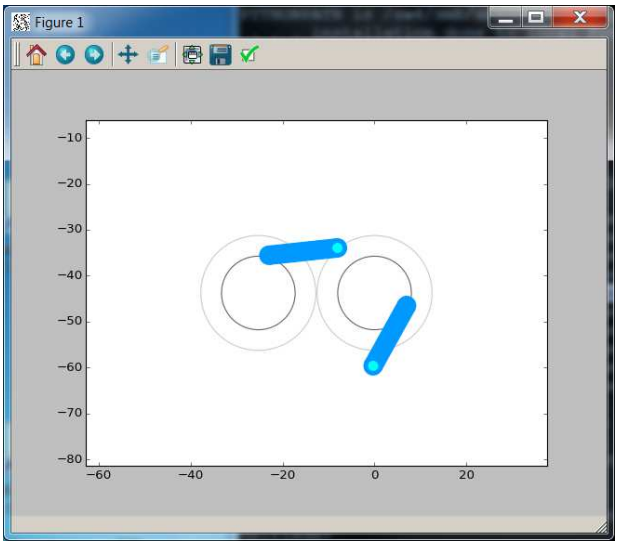






Note that this difficult situation can be avoided by a different choice of parity settings, as shown below. This configuration has a lower “degree of difficulty” estimate (0.144 compared with 0.270). With the new parity settings, the path analysis software is able to reach the targets.



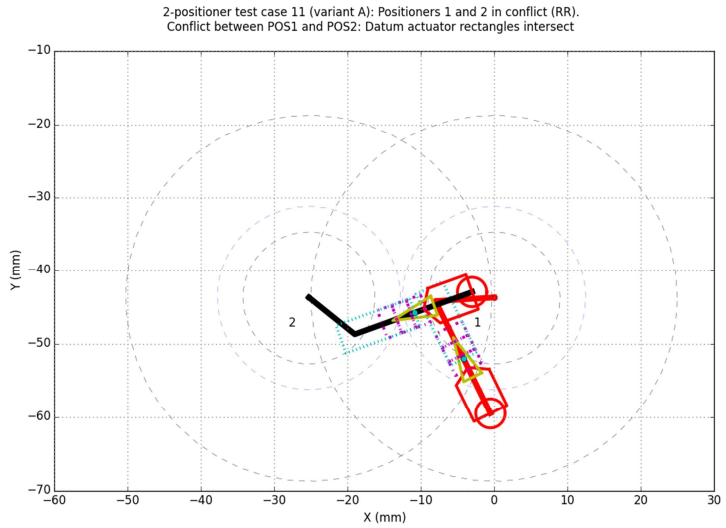


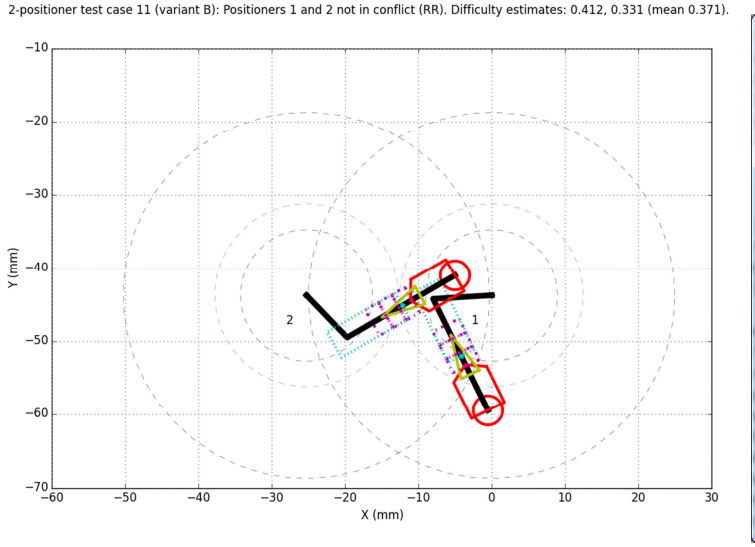
2.7 Test Case 11

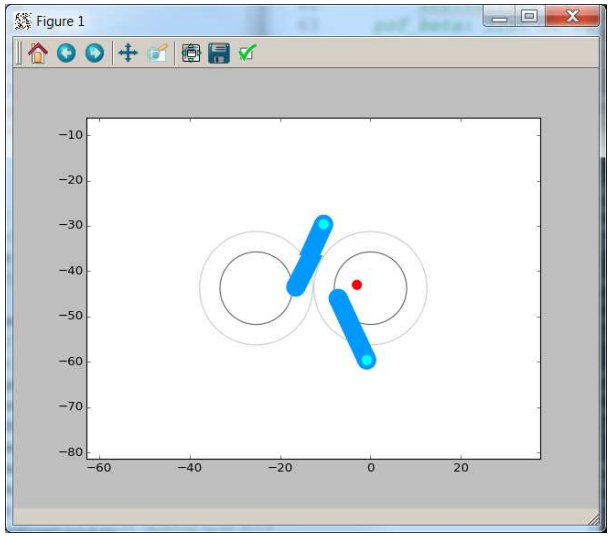
Table 2-12: Two Positioner Test Case 11 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	59.502	180.481	-0.50	-59.50
	B	“	“	“	“
2	A	43.105	183.991	-3.00	-43.00
	B	41.304	186.953	-5.00	-41.00

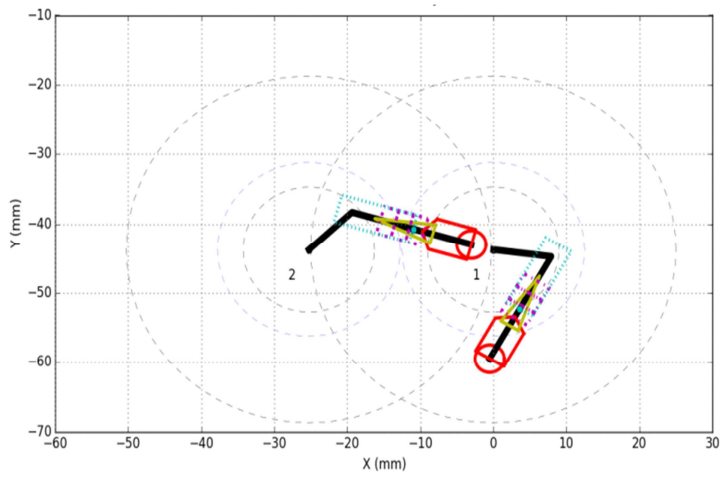
Scenario variation A is prevented by the conflict checking software (datum actuators intersect). The path analysis software deadlocks in both variations A and B.

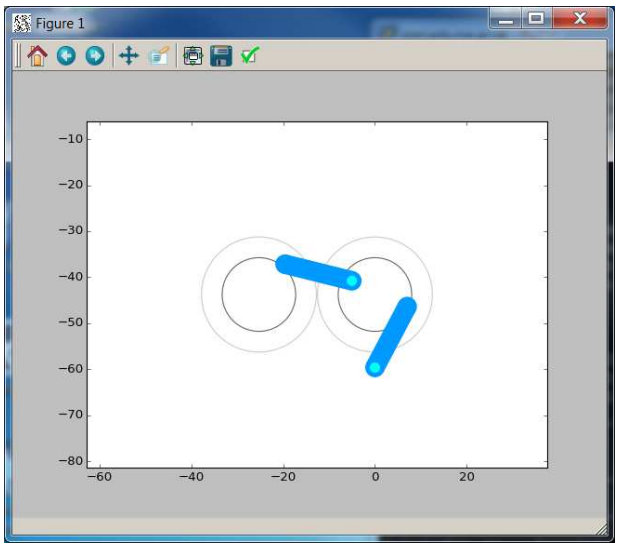






Note that this difficult situation can be avoided by a different choice of parity settings, as shown below. This configuration has a lower “degree of difficulty” estimate (0.210 compared with 0.371). With the new parity settings, the path analysis software is able to reach the targets.





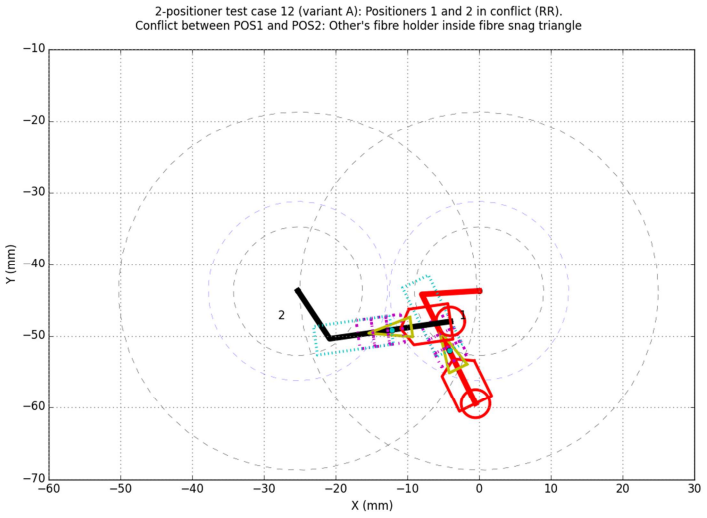
2.8 Fibre Snagging on Beta Arm

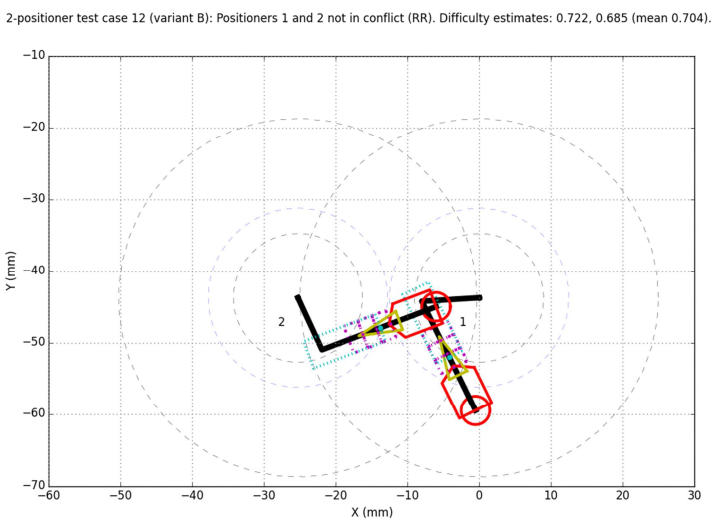
2.8.1 Test Case 12

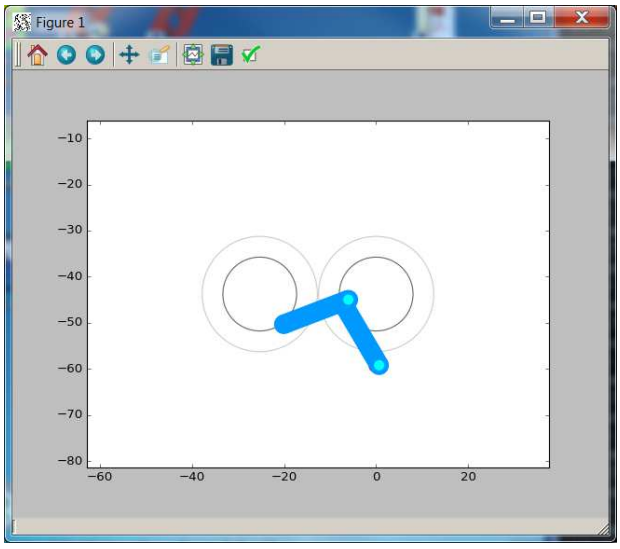
Table 2-13: Two Positioner Test Case 12 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	59.502	180.481	-0.50	-59.50
	B	"	"	"	"
2	A	48.166	184.764	-4.00	-48.00
	B	45.398	187.595	-6.00	-45.00

Scenario variation A is prevented by the conflict checking software (fibre holder inside fibre snag zone). The path analysis software deadlocks with variation A but succeeds with variation B.







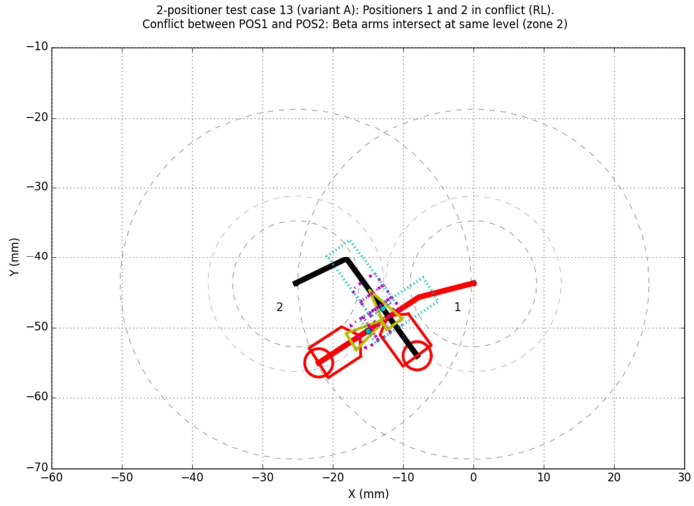
2.9 Beta Arm to Beta Arm

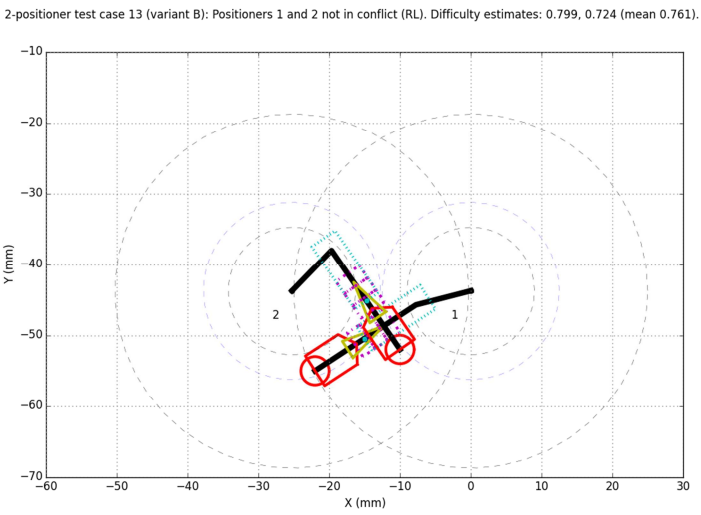
2.9.1 Test Case 13

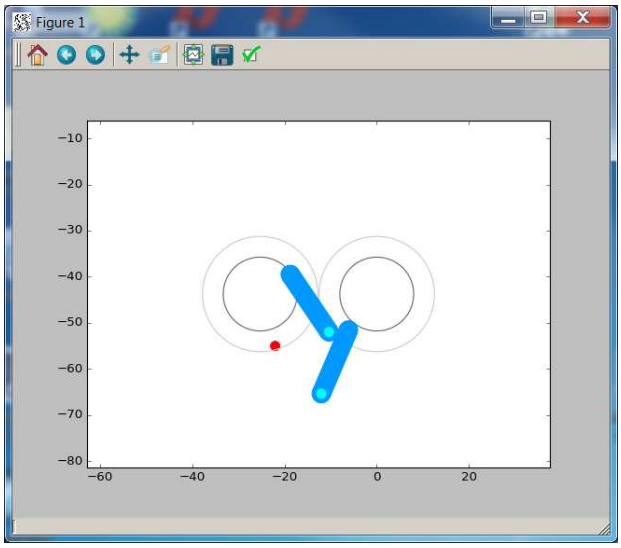
Table 2-14: Two Positioner Test Case 13 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	A	59.237	201.801	-22.00	-55.00
	B	"	"	"	"
2	A	54.589	188.427	-8.00	-54.00
	B	52.953	190.886	-10.00	-52.00

Scenario variation A is prevented by the conflict checking software (beta arms cross). The path analysis software deadlocks in both variations A and B. Positioner 1 goes the wrong way round (clockwise) and cannot pass through positioner 2.







2.10 Path Analysis Test Cases

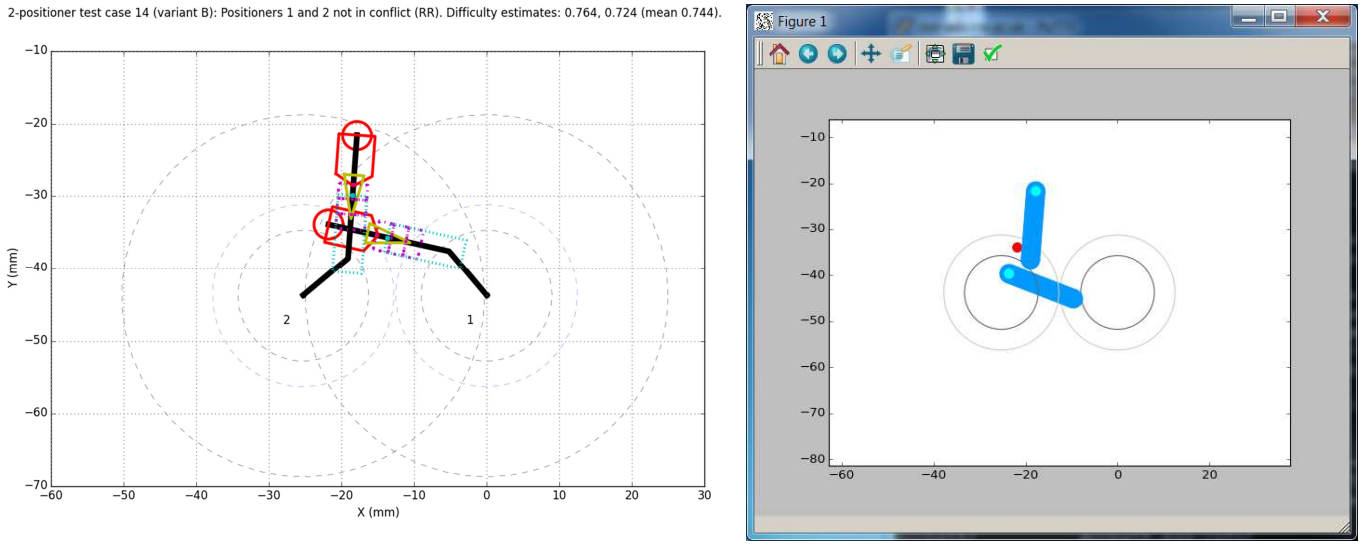
2.10.1 Test Case 14

This is a test case for the path analysis software, specified by Laleh Makarem, so there is no variation A. The fibre positioners are not in conflict.

Table 2-15: Two Positioner Test Case 14 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	B	40.3434	212.668	21.776	-33.962
2	B	28.0970	219.449	-17.853	-21.696

The path analysis software deadlocks.



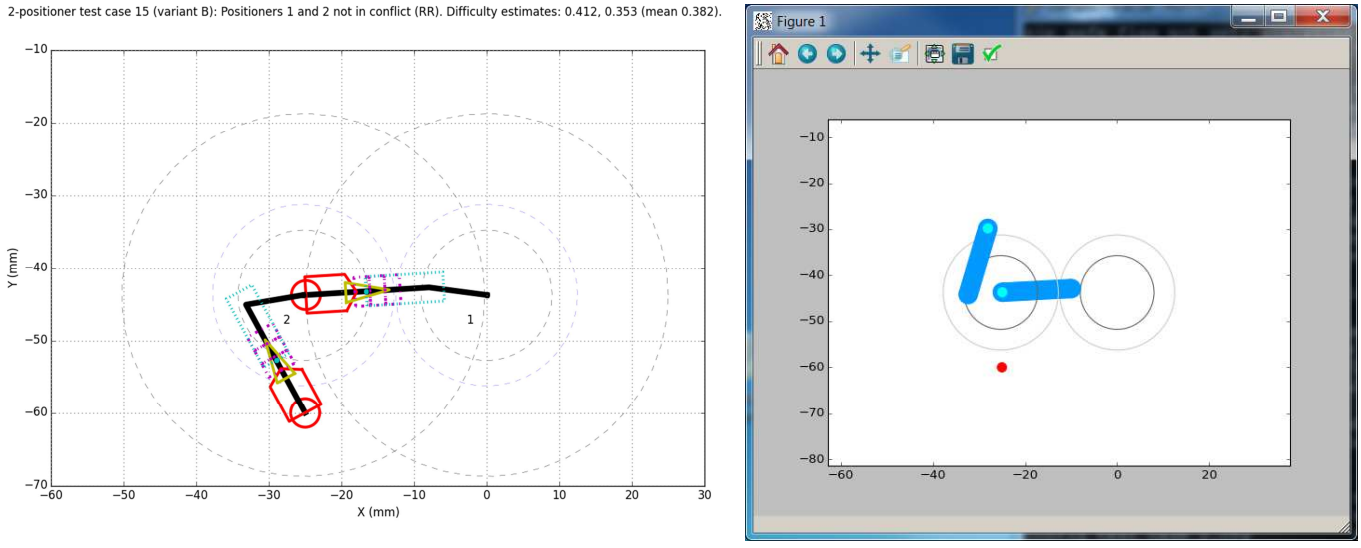
2.11 Test Case 15

This is a test case for the path analysis software, so there is no variation A. The fibre positioners are not in conflict.

Table 2-16: Two Positioner Test Case 15 Targets

Fibre positioner	Variation	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	B	50.3396	209.646	-24.900	-43.750
2	B	65.0000	202.620	-25.000	-60.000

The path analysis software deadlocks. Positioner 2 attempts to reach its target in the wrong direction (clockwise) and meets positioner 1.



2.12 Conclusions for Two Positioner Test Cases

- The conflict checker software passes its most critical tests by detecting the collision scenarios represented by variation A of the test cases. These test cases must be checked with the prototype fibre positioner cluster to ensure that the mechanical avoidance zones are accurately represented in the software.
- The path analysis software passes its most critical tests by avoiding a collision during all these test cases, ending in either success or deadlock.
- The path analysis software appears to be too conservative to allow MOONS to pick off close targets. All the B variations of the test cases resulted in deadlock except for test case 7.
    - In many of the test cases (1, 2, 3, 4, 5, 13 and 15), the situation results in deadlock because one of the positioners sets off in the opposite direction than the one obvious to the human eye.
    - Test cases 1, 2, 3, 4 and 13 would only succeed if the positioner that has already reached its target moves aside to let the other one pass.
    - Test cases 6, 10 and 11 are deadlocked because repulsion between the datum actuators has an amplified effect on the beta arm angle. It might not be possible to avoid these deadlocks without causing glancing collisions between the datum actuators while moving. In any case, 6 is a very difficult scenario to achieve.
    - Test cases 5, 8, 9 and 12 come close to succeeding. These might succeed if the repulsion zone parameters within the path analysis software are optimised, or the repulsion effect reduced as the positioners approach their targets. But how do you distinguish these scenarios from the ones which would result in a collision if you reduced the repulsion effect?
- In many cases, the “degree of difficulty” parameter will help find the best parity combination for the path analysis software, but in some cases (such as test case 6) the path analysis deadlocks whatever parity settings are used.

3 Four Positioner Test Cases

The fibre positioner grid has a small number of regions where 4 close targets could theoretically be picked off by the fibre positioners. The one test case tests whether it is feasible for the path analysis software to achieve such a configuration.

3.1 Fibre Positioner Configuration

These four positioner test cases use fibre positioners whose centres are located in MOONS focal plane coordinates as defined in the following table.

Table 3-1: Four Positioner Configuration

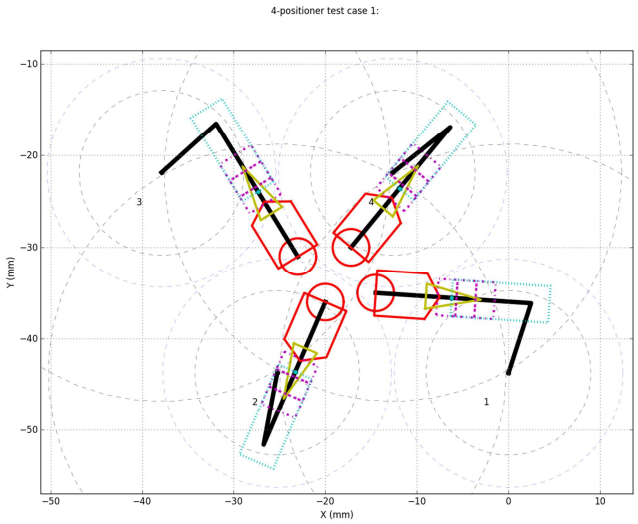
Fibre positioner	POS RFOCAL (mm)	POS THFOCAL (deg)	POS ORIENT (deg)	POS YFOCAL (mm)	POS ZFOCAL (mm)
1	43.74780	180.0000	0.0	0.000	-43.748
2	50.51471	210.0000	0.0	-25.257	-43.748
3	43.7478	240.0000	0.0		
4	25.2588	210.0000	0.0		

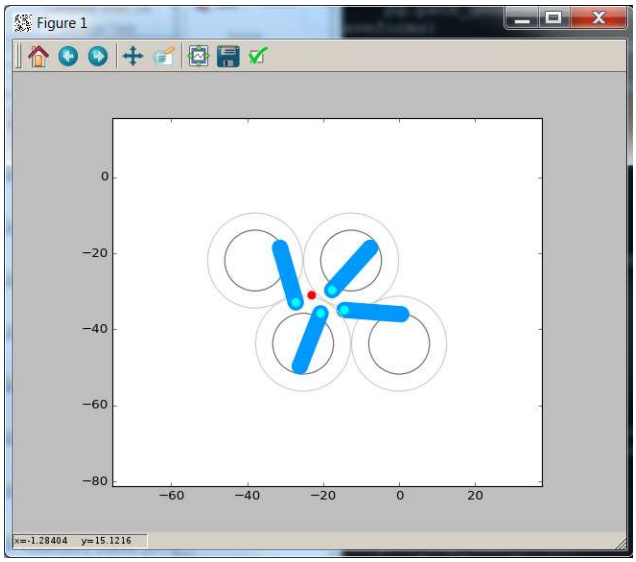
3.2 Test Case 1

Table 3-2: Four Positioner Test Case 1 Targets

Fibre positioner	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	37.885	202.504	-14.5	-35.0
2	41.183	209.055	-20.0	-36.0
3	38.601	216.573	-23.0	-31.0
4	34.581	209.827	-17.2	-30.0

The path analysis software reaches 3 out of the 4 targets. Positioner 3 deadlocks because its target is too close to positioners 2 and 4.





3.3 Conclusions for Four Positioner Test Cases

- The path analysis deadlocks because the other positioners are too close to the target, even though there appears to the human eye to be a collision free path. This may affect the ability of the MOONS fibre positioner to reach close targets.

4 Six Positioner Test Case

It is theoretically possible for the 6 positioners neighbouring a central positioner to reach targets placed close to its centre. The one test case tests whether it is feasible for the path analysis software to achieve such a configuration.

4.1 Fibre Positioner Configuration

These six positioner test cases use fibre positioners whose centres are located in MOONS focal plane coordinates as defined in the following table. Note there are 7 positioners because the 6 being tested are neighbours of a 7th.

Table 4-1: Seven Positioner Configuration

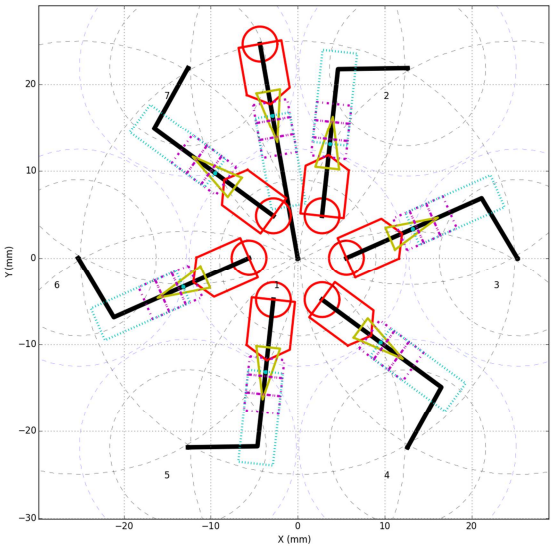
Fibre positioner	POS RFOCAL (mm)	POS THFOCAL (deg)	POS ORIENT (deg)	POS YFOCAL (mm)	POS ZFOCAL (mm)
1	0.00000	90.0000	0.0		
2	25.25870	30.0000	0.0		
3	25.25870	90.0000	0.0		
4	25.25870	150.0000	0.0		
5	25.25870	210.0000	0.0		
6	25.25870	270.0000	0.0		
7	25.25870	330.0000	0.0		

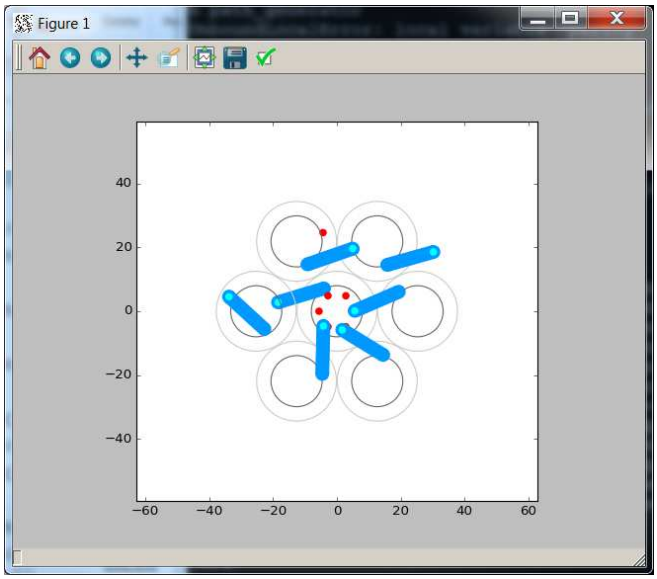
4.2 Test Case 1

Table 4-2: Six Positioner Test Case 1 Targets

Fibre positioner	FIBRE RFOCAL (mm)	FIBRE THFOCAL (deg)	FIBRE YFOCAL (mm)	FIBRE ZFOCAL (mm)
1	25.0000	350.0000		
2	5.6000	30.0000		
3	5.6000	90.0000		
4	5.6000	150.0000		
5	5.6000	210.0000		
6	5.6000	270.0000		
7	5.6000	330.0000		

The path analysis software reaches only 2 out of the 6 targets. The positioners 2, 6 and 7 at the top are deadlocked by the central positioner trying to get out of the way. Positioner 4 deadlocks because its target lies between two other positioners.





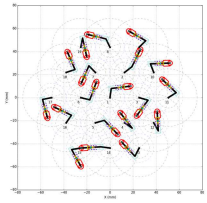
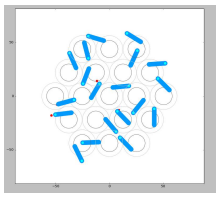
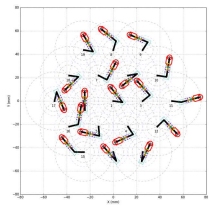
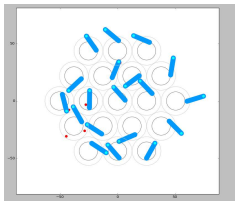
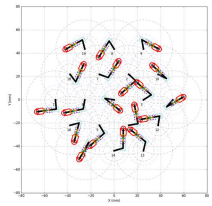
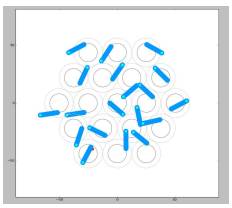
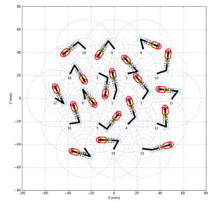
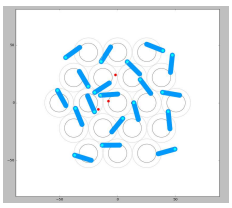
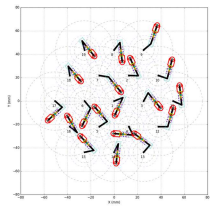
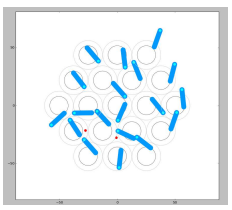
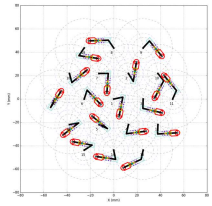
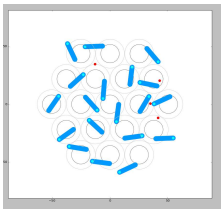
4.3 Conclusions for Six Positioner Test Case

- The test case is theoretically possible but cannot be achieved in reality.
- The path analysis deadlocks because the other positioners are too close to the target, even though there appears to the human eye to be a collision free path. This may affect the ability of the MOONS fibre positioner to reach close targets.

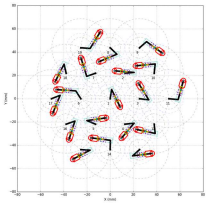
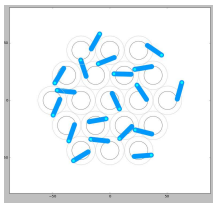
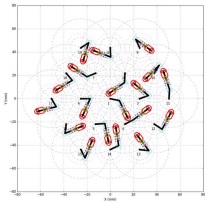
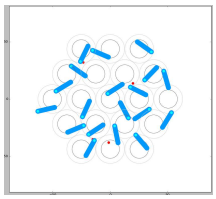
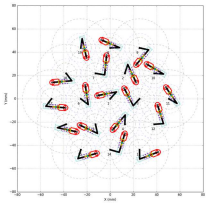
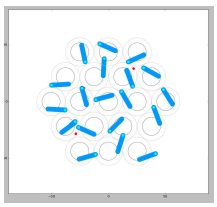
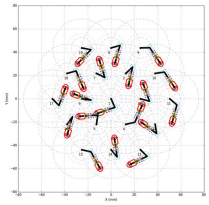
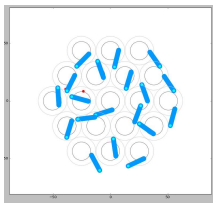
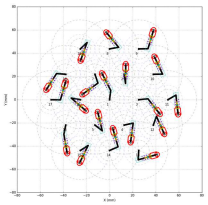
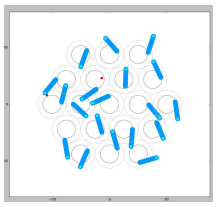
5 Nineteen Positioner Test Cases

The higher-level functionality of the path analysis software can be tested by running a series of tests using a 5 x 5 hexagonal grid of 19 positioners. For each test, targets locations are chosen randomly until each positioner can reach a target without a conflict in the final configuration. (In these tests collisions are detected by carefully watching the animation generated by the path analysis simulation.) The ability of the path analysis software to reach those targets without a collision or deadlock is then tested. The following table shows the results for 11 different tests.

Table 5-1: Nineteen Positioner Test Results

Test	Conflict check diagram	Path analysis diagram	Success	Deadlock	Collisions!
0			15	4	1[1]
1			15	4	0
2			18	1	0
3			16	3	0
4			17	2	0
5			15	4	0

[1] The collision was caused by a bug in the path analysis algorithm, which has now been corrected.

6			19	0	0
7			16	3	0
8			17	2	0
9			17	2	0
10			17-18?	1-2?	0

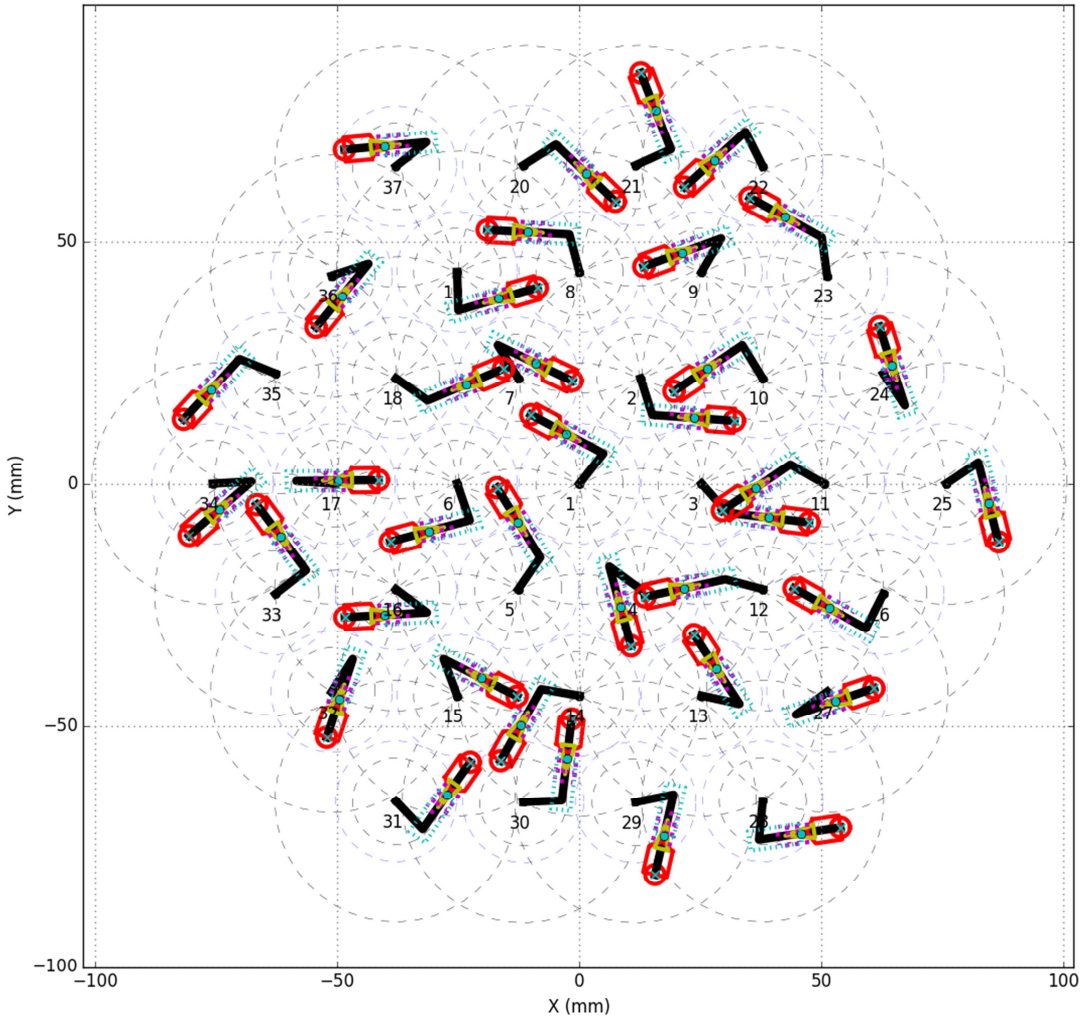
After each new release, the path analysis software must run a series of these random tests without a collision before it can be used to control fibre positioner hardware.

5.1 Conclusions for Nineteen Positioner Tests

- The first test failed because positioners 14 and 15 collide. This problem was caused by a bug in the path analysis software, which has now been corrected.
- In the last test the path analysis software reports that it has reached 18 targets, but the animation clearly shows that only 17 targets have been reached. This was also caused by a bug, which has been corrected.
- The path analysis software achieves a success rate of between 15/19 (79%) and 19/19 (100%). This is less than the 85%-95% success rates reported by the OPS simulations, but more than the success rate of the 2-positioner test cases. Random tests are harder to achieve than OPS tests because the OPS optimises the choice of targets before sending them to the path analysis software.
- In those tests with a low success rate, the path analysis software shows similar behaviour to that seen in the 2-positioner test cases. Some positioners move in a non-optimum direction and end up being blocked by another positioner; others cannot reach their targets because they are two close to another positioner.

6 More Random Tests

It is possible to repeat the random tests described in section 5 with larger simulations, such as the 7 x 7, 37-positioner test shown here:



The main difference is that is harder to spot by eye when a collision happens. For these larger tests, collisions can be detected by simulating the execution of the path analysis waveform and running the conflict checker after each waveform step.