

1703018

by Amelia Boettcher

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FACULTY OF ARCHITECTURE, COMPUTING AND ENGINEERING

**B.ENG. (HONS) MECHANICAL AND MANUFACTURING
ENGINEERING**

2019

MAJOR PROJECT – M600417

**THE INVENTION OF AN ALIGNMENT JIG FOR
THE MANUFACTURE OF A MAGNIFICATION
OPTICAL SYSTEM FOR SPECTROSCOPY**

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: A Böttcher

Date: 30th April 2019

Acknowledgements

Firstly, I wish to thank PerkinElmer for the chance to undertake this project within the company whilst completing an undergraduate Engineering Degree. I would like to express my gratitude to Dr Lewis Jones for his patience mentoring me throughout the project. I owe a lot of gratitude to Dr Arnaud Marotin for being a great supervisor and coming to visit the manufacturing site. I wish to thank the leader of Product Lifecycle Engineering, Mohinder Singh for supporting the insourcing project by allocating his time and resources. I appreciate the help provided by the Spotlight assembly line Spencer and Wayne for sharing their knowledge and expertise about the instrument.

Abstract

PerkinElmer

PerkinElmer is an American company founded in 1937 (Fig 1) by Richard S. Perkin and Charles W. Elmer, a banker and court reporter respectively (PerkinElmer, 2018). They joined together to begin an optics design and consulting business from their shared affection for astronomy. Now a team of 11,000 across the world provide customers with diagnostics, life sciences and environmental health solutions. PerkinElmer has a manufacturing site in Llantrisant, Rhondda Cynon Taff, South Wales assembling over twenty different types of scientific instruments. The site is growing and developing over time adding new production lines year on year.



FIGURE 1 ESTABLISHING PERKINELMER

Task

To design and produce a working alignment jig to produce an assembly on PerkinElmer's manufacturing site which provides the Spotlight 400 Spectrometer a working magnification system. This must allow for the correct alignment of the lenses and mirrors within the magnification. Proficient understanding of the alignment process is a must, in order to adapt to using another jig made from another company with no supplied documentation.

Solutions

Taking vital information from archived Research and Development documentation for the components within the magnification system, develop a new jig from available knowledge and use it towards inventing a new approach to assembling the component making any improvements as necessary.

Results

Sadly, due to a strategic decision made by the PerkinElmer midway through the project, the company no longer require an internally developed jig, therefore this project will be developing the jig as far as possible. Researching new methods into optical alignment have surfaced along with the ability to confidently operate a new magnification jig.

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Chapter 1: Project Introduction and Project Definition

Introduction

Inside PerkinElmer's top of the range Fourier Transform Infrared Spectrometer, the Spotlight 400, is the assembly housing an optical system to give the user of the instrument the option to magnify the image of the inspected specimen. Inside the magnification assembly, lies a tube in which the optics which produce the magnification sit inside cavities, bonded to the walls of the tube. This tube named the 'Z fold Tube' due to its characteristic Z shape of the light path traversing inside. PerkinElmer wishes to insource the manufacturing of the magnification system from an overseas company who machines and assembles components. The project was raised as an opportunity to accrue savings of up to £400,000 a year, found from changing supplier and assembling the assemblies on the Llantrisant site.

Llantrisant Manufacturing Site

PerkinElmer has manufactured analytical and diagnostic instruments in Llantrisant for over thirty years (PerkinElmer, 2018). It is the businesses sole manufacturing site in the United Kingdom amongst seven others on globe. The Research and Development site is in Beaconsfield, England which supports manufacturing and development of the instrumentation across the company, consulting with this department closely can release important historical data and employee expertise.

Llantrisant builds and tests approximately twenty different instruments turning over \$200,000,000 annually. The sites manufacturing is divided into two sectors of the PerkinElmer company; Life Sciences and Environmental health. The Life Sciences department produces instruments for the following, high content screening, high content analysis, multi label plate readers, multimode micro plate readers, prion tomographs and confocal microscopes. These are used in the field to provide medical laboratories, researchers, clinicians and hospitals with assay platforms and software in the instrument. The Environmental Health sector of the site manufactures for a broad range of end users who which to carry out material characterisation and thermal and elemental analyses using the following instruments with Ultra Violet, Visible and Near Infrared Spectrometers, Fluorescence spectrometers, Differential Scanning Calorimeter, Elemental Analysis, Fourier Transform Imaging and Spectroscopy with supplementing software.

Aims and objectives

To insource elements of assembly otherwise made externally incurs a cost saving for the business. The project is to insource all subassemblies involving any dichroic mirrors within the Spotlight. Four assemblies are mechanical with optics mounted inside. All four are universal to all Spotlight models apart from a magnification feature available on one model variant. In order to assemble the components an alignment jig must be made to align the optics within the magnification tube before bonding.

The approach to this project will be both quantitative and qualitative in nature with research methodologies originating from experiments. Useful data for the analysis of quantitative and qualitative results will be gathered and examined for the project from June 2018 to April 2019.

A key deliverable in this project are to increase the capability of the optics manufacturing department within the plant thus enabling the company to take on more work and increase productivity.

The scope of work involved, spans internal departmental boundaries, blending Research and Development, Product Life Cycle Engineering and the Manufacturing together.

Limitations

Financial constraints are made by the Product Life Cycle Engineering department for this Insourcing project. Depending on the cost saving figures produced, different levels of financial ceilings are created. The company is also bound by a contract with the current outsourced assembly featured in this project restricting movement. An established relationship with the supplier through a contract states that if PerkinElmer were to pull out an element of an assembly for insourcing, the whole build would have to be pulled too. Consequently, if the essential component which requires precise alignment, upon insourcing, the means of assembling it are now up to us. PerkinElmer's Strategic Purchasing department works concurrently with Product Life Cycle Engineering to make key strategic multi departmental decisions. Due to the sensitivity of the relationship between the vendor and PerkinElmer, reaching out to retrieve the means of aligning a product that is already owned by PerkinElmer is perceived as uncouth and forward. Proving that in Beaconsfield and in Llantrisant, there is no longer strict control, understanding or ownership of some of its assemblies made overseas.

Project plan

Over the course of the project the following plan was made and put in place.

 = Critical Path

Task 1- Optical Design

- Lens design software proof of concept (BC 16/11/18, WC 23/11/18)
- Creation of correct optical environment for z fold, reverse engineering then redesigning system (BC 30/11/18, WC 14/12/18)
- Creation of lens retention mechanism (BC 3/12/18, WC 21/12/18)
-  Testing, proof of concept (Focus position) (BC 5/12/18, WC 18/1/18)

Completion Task 1 Best Case=5/12/18, Worst Case=18/1/19

Task 2 – Fixture Design

-  Design and test of positioning mechanism (BC 7/1/19, WC 11/1/19)
-  Design and test of top spheroid positioning (BC 7/1/19, WC 11/1/19)
-  Design and test of bottom spheroid positioning (BC 7/1/19, WC 11/1/19)
-  Z fold tube positioning mount/aid design (BC 18/1/19, WC 31/1/19)
- Camera positioning (BC 18/1/19, WC 21/1/19)
- Design of data acquisition and operator interface (BC 18/1/19, WC 21/1/19)
- Base plate manufacture (BC21/1/19, WC1/2/19)

Completion Task 2 Best Case=21/1/19, Worst Case=1/2/19

Task 3 – Testing

- Define candidate SOP for testing (BC 21/1/19, WC 23/1/19)
-  Test stability of laser system (BC30/1/19, WC 8/2/19)
- Glue testing (BC4/2/19, WC10/2/19)
 - Brass mount for optics (dummy z fold base)
 - Evaluate optical drift during curing

Completion Task 3 Best Case=, Worst Case=

Task 4 – Adapting design for manufacture

- Dry run of SOP with candidate operators (BC 5/2/19, WC 30/2/19)

- Refine jig fixture design (BC5/2/19, WC 30/2/19)
- Refine SOP (BC 5/2/19, WC 20/2/19)
- R&R (BC 5/2/19, WC 20/2/19)

Completion Project Best Case=5/2/19, Worst Case 20/2/19

Task 1 Breakdown – Optical Design

- Establish how to use Winlens3D (Qioptiq)
- Create system of multiple lenses on software
- Create beam expander lens on 3D printer
- Find angle required to achieve adequate cover of the entry flat mirror in Z fold
- Translating ray diagrams from optical software into SolidWorks
- Edmund optics beam expander lens ran out of stock, catch up of when it is due
- Query black optical coating
- Create EC on drawing for paint when insourcing
- Recreate black optical coating
- Create SOP for painting/masking process
- Invent new method for aligning both spheroids simultaneously

Task 2 Breakdown – Fixture Design

- Attach positioning mechanism to breadboard
- Correctly align optics
- Must pass focus test with no Z fold
- Design and 3D print mount for Z fold
- Decide on camera positioning
- Create adaptors for baseplate if required
- Design baseplate
- Receive base plate
- Attach parts onto baseplate

Task 3 Breakdown – Testing

- Create SOP during R&D phase and cross reference
- Build test for laser stability
- Must pass focus test with Z fold in place
- Machine brass mounts to test glue on optics
- Meet and Discuss with R&D

Task 4 Breakdown – Adapting design for manufacture

- Gather feedback from dry run
- Reevaluate design, poke yoke analysis
- Analyse

Chapter 2: Literature Review

Spectroscopy

Spectroscopy is the general method of study of the pattern produced when an energy source hits a material sample. There are hundreds of combinations of this technique to obtain data on a samples response to an electromagnetic beam. The response is shown in the form of a spectrum which is analysed to extract the information required. The goals of spectroscopy are to obtain quantitative data and understand readings like you would another measurement like a clock or ruler (Tokmakoff, 2003, p. 1).

Principles

A spectroscopy system excites and detects molecules within a sample by absorption, emission or optical rotation.



Figure 2 – Diagram showing basic principles of spectroscopy

In the majority of spectroscopy methodologies, the samples character is found from the change in light after it has passed through with a detector. In absorption, the change of the intensity of the incident light is measured, along with frequency/wavelength. In an emission system, the exited sample molecules emit light in all directions which lands on the detector. Emission systems include; fluorescence, where some molecules absorb and emit light of longer wavelengths than others after a brief interval called fluorescence lifetime (Davidson, 2003), Phosphorescence from electrons excited in a triplet state and Raman Scattering from electrons vibrating in their transition. The third method is to measure optical rotation, by recording the rotation of polarisation. There are two types of spectrometers, Fourier transform and dispersive.

Microscopy

Looking at Antony Van Leewenhoek a Dutch scientist invented the first microscope in the late 17th century (Vision Engineering, 2015). His most successful microscope was a simply polished glass sphere that sits within a metal holder which could achieve a great increase in magnification power compared to its predecessors, 270x compared to 50x. For the first time, samples that could otherwise not be seen under the naked eye were now viewed such as bacteria, yeast and blood cells. In order to reach higher levels of magnification, one has to layer lenses upon one another. This is called a compound microscope; the term currently used for these is now shortened simply to microscope. Microscopes today can now yield chemical information by using more than the visible light spectrum.

IR Microscopy

PerkinElmer was a pioneer in the 1940's and 1950's using the Infrared spectrum within a microscope system (Suzanne McFarlane, 2009). Their flagship commercial IR microscope was the Model 12 IR Spectrophotometer in Figure 2 available to the scientific community.



Figure 3– Depicts the scale of early PerkinElmer instruments (PerkinElmer, 2018, n.d)

PerkinElmer has been manufacturing the same instrument with different versions for over 60 years (PerkinElmer, 2018) as shown in Fig 4.

Fourier Transform Spectroscopy

Joseph Fourier (1768-1830) observed that a composite signal can be written again as an 'infinite sum of simple sinusoidal waves' (JF, 2002). Applications of the concept create the form of music, voice, image into the digital form (Gallagher & Nemeth, 2008).

Fourier Transform Spectroscopy is a method of measuring data of spectra from the coherence of its source, using time or space domain measurements from the electromagnetic radiation. A Fourier Transform changes a complex signal into a simple wave. It is a fundamental tool to allow a user to clearly view the frequency and amplitude parts within. This can be used in many spectroscopy types such as Magnetic Resonance Imaging (MRI) (Gallagher & Nemeth, 2008).

Fourier Transform Infrared Spectroscopy FTIR

IR Microscopy Experience



1954



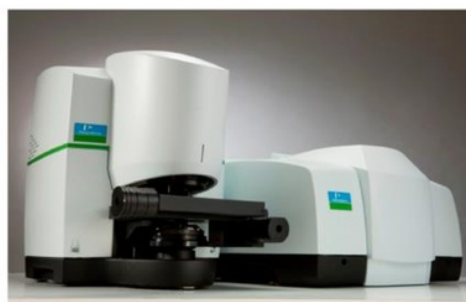
1984



1990



1994



Current

Figure 4 : shows the sustaining of IR Spectroscopy instruments within Perkin Elmer (PerkinElmer, 2018)

Current range of Microscope and Imaging Family

Currently the company produces four instruments using microscopy and imaging techniques which better apply to a customer's application and requirements. The Multiscope is the entry level microscope which is entirely manual, with manual stage and apertures. The Llantrisant site produces three main variants; Spotlight 150i, 200i and 400. The three versions are available to upgrade from one model to the next with complex modifications and are available with a variety of accessories which makes the system highly configurable. The Spotlight system is the microscope paired with either a Frontier or Spectrum instrument. The Frontier is the spectrometer element which connects to the side of the Spotlight; the Spectrum instrument is a compact version of the comparatively large Frontier as shown in Figure 5. The Spotlight 150i is a single point mode detector with a manually adjustable stage. The 200i contains an automated stage and control. The 400 contains the same automated stage but with a detector containing multiple points in an array.



Figure 5 – Spotlight, Spectrum and Frontier (PerkinElmer, 2018)

Spotlight 400

The front runner of the Spotlight series due to it being the best equipped in the range. There are functionalities and parts included that are not available on the other models. This includes the magnification system which this project focuses on.

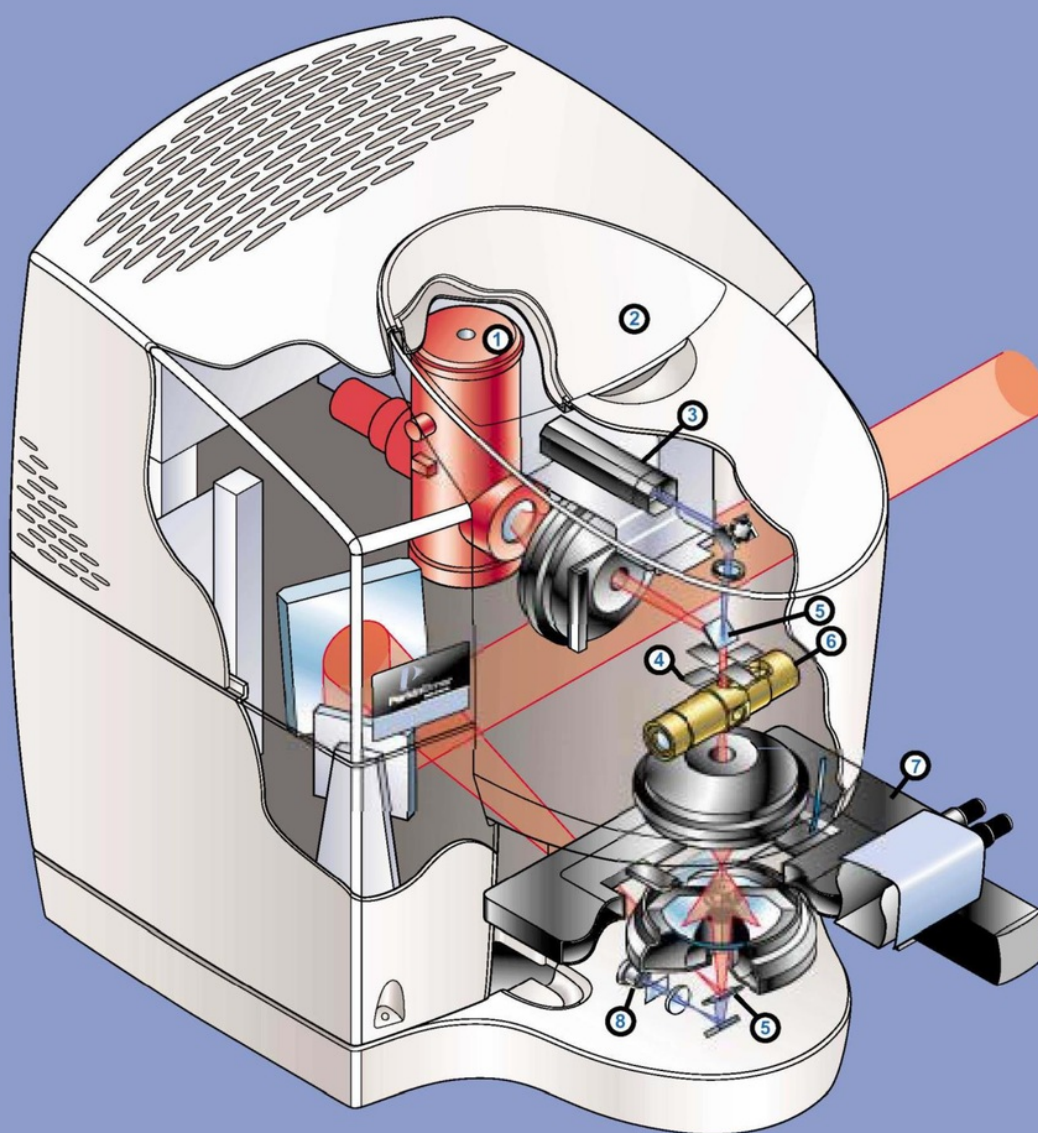


Figure 6 The interior Mechanisms of the Instrument (PerkinElmer, 2018)

Figure 6 illustrates a view of the interior of the Spotlight 400 and the below features.

1. MCS Detector
2. Access lid to feed liquid nitrogen to the detector
3. 64 Bit camera
4. Aperture plates
5. Dichroic mirrors
6. Z fold tube
7. Stage
8. LED bulb

MCS Detector

Mercury Cadmium Telluride is used within the photo-detector in the Spotlight 400 and other available Fourier transform infrared spectrometers. This is due to its wide spectral range, array size, cooling requirements, long wavelength application of photovoltaic technology, three colour and readout capability (Zandi & Wijewarnasuriya, 2009). The specific detector unit used is custom built by Leonardo and is a 'single element medium band MCT detector and dual mode detector (Duet) containing single element and array detector' (PerkinElmer Inc, 2013). The aperture plates change the modes in which the detector can be used; point mode or imaging mode (Fig 8).

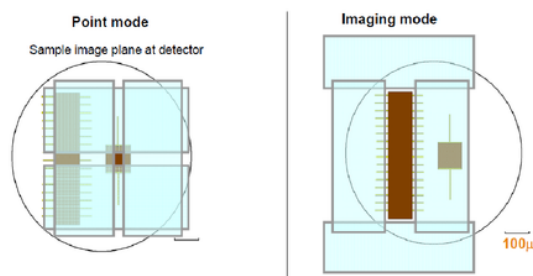


Figure 7: Detector mode selection (Wita, 2014)

Cold Shielding

Liquid nitrogen needs to be fed inside a chamber that surrounds the MCS Detector to provide a cold shield as IR detects are most accurate when protected from stray IR rays and latent heat (Pheonix Eceltroformed Products Inc, 2018). The Dewar provides 18 hours of instrument cool time (PerkinElmer Inc, 2013).

Camera

Integrated camera provides the software and user with a live video image of the sample. It can sample points for all data collection modes and are defined by interacting with it directly. The camera has been recently upgraded to 64 bit from 32 bit to support newer versions of windows software.

Dichroic Mirrors

Dichroic mirror coating allows the surface to reflect a band of wavelengths of some light and allow other bands of light at certain wavelengths pass through. Using these types of mirrors creates a working dual use for two optical systems meeting at the same plane. The insourcing project came about from the specifications of the dichroic mirror system found within the Spotlight in addition to the magnification system not being up to specification.

Z Fold tube

The Z fold tube is a magnification system that provides automatic switching between wide area survey and high definition imaging modes. The tube magnifies the image by four times and allows 25 or 6.25µm pixel resolution.

Optical Functionality

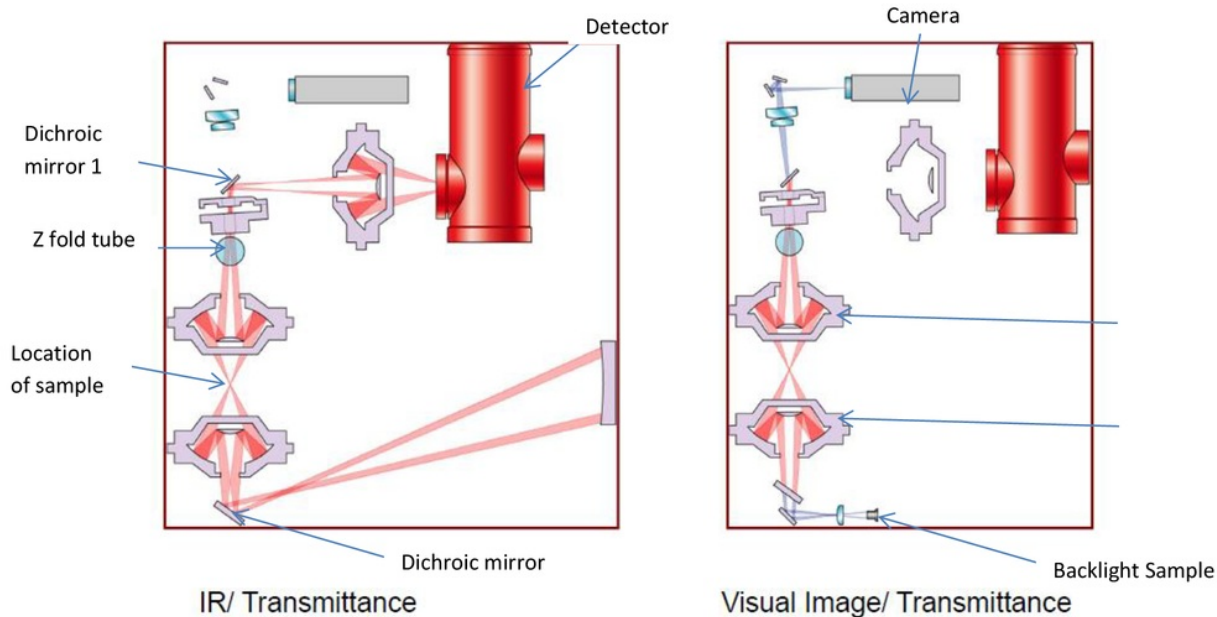


Figure 8 Optical system Within a Spotlight 400 on Transmittance Mode (Suzanne McFarlane, 2009)

IR / Transmittance Mode

- ▶ Energy from a laser in a neighbouring Frontier machine enters the Spotlight from the side
- ▶ Two toroid mirrors direct the beam of energy to the lower polarising mirror
- ▶ The beam travels through the lower cassegrain hitting the secondary convex mirror then the primary concave mirror and focusing on the sample
- ▶ The transmitted beam travels through the sample and up to the upper cassegrain, hitting the primary concave mirror then the secondary convex mirror
- ▶ The beam now passes through the open hole in the z fold tube and the aperture focusing on the upper dichroic mirror (0290)
- ▶ The beam passes through the final MCT detector cassegrain into the MCT detector
- ▶ The detector then feeds its results from the energy readings of the sample into software for the user to determine the samples properties

Visual Image/ Transmittance

- ▶ The 64bit camera picks up images from the light of the LED at the very bottom of the machine
- ▶ The LED beam initially travels through a diffuser lens and reflected off a mirror and through a dichroic mirror

- ▶ The beam now enters the lower cassegrain hitting the interior mirror, expanding to the walls of the cassegrain and out the other side through the narrow gap
- ▶ The Light is now focussed onto the specimen transmitting through to the upper cassegrain
- ▶ Once through the upper cassegrain it enters the z fold tube through the magnification assembly to another dichroic mirror
- ▶ Reflecting off additional lenses to narrow the beam it finishes its journey at the camera, showing the user what it sees inside the specimen through the LED light

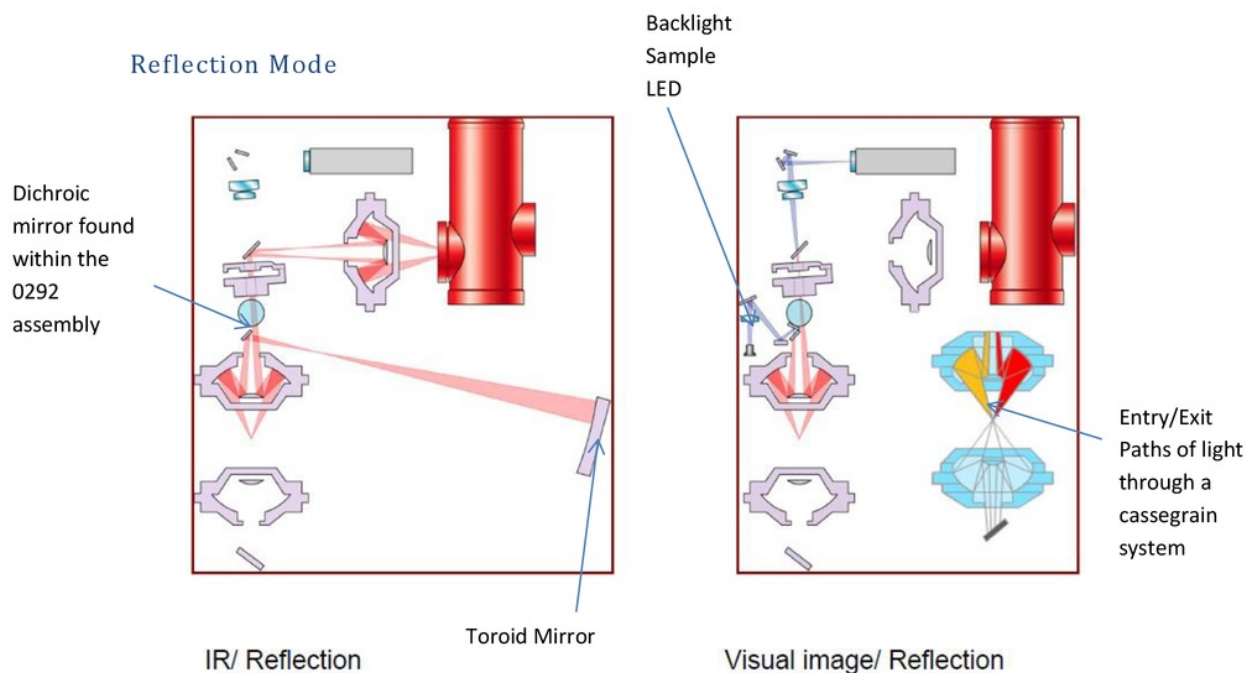


Figure 9 Optical Path within the Instrument on Reflection Mode (PerkinElmer, 2018)

IR/ Reflectance Mode

- ▶ The Infrared Source comes from an instrument which the Spotlight is paired with i.e. Spectrum 2. The source rays reach the Spotlight through matching holes at the sides of the instrument which are aligned during the install of the instrument at the clients site by PerkinElmer employees/technicians in the field
- ▶ The source is targeted to the toroid mirror at the lower right corner in Figure 9, IR/ Reflection
- ▶ The toroid mirror directs the beam to a mirror found in the 0284 assembly, travels down into the upper cassegrain to the sample and back up the cassegrain
- ▶ The light passes through the Z fold tube up through the cavity in the magnification housing reflecting off a dichroic found in the 0290 assembly, expanded through the detector cassegrain and finally detected by the detector

Vis/ Reflectance Mode

- ▶ The light originates from another LED light in the centre of the machine, diffused before hitting the first reflective mirror onto a dichroic found in the magnification system

- ▶ Light is reflected down through an additional mirror into the upper cassegrain focussing onto the sample then traveling back up the cassegrain as shown in blue on the bottom right of the Visual Image/Reflection in figure 9 above
- ▶

Project viability

The project is assessed for viability from calculations based upon labour rates on estimated build times along with new quotes of machined parts from an alternative supplier. The change in supplier is to further reduce costs while the opportunity to change is available. If the calculated estimated cost savings are great enough then the project is approved by the Insourcing Team.

The drive for the insourcing of these assemblies originates from the current supplier being unable to consistently produce dichroics which are to specification as shown by the variation in results found below from the results obtained when comparing dichroic coatings. This test was made in the range of 800-7800cm⁻¹. The blue trend shows the mirrors which are to specification and the pink trend indicates the older dichroic. These results show the reflectance which is the metric used to measure the component against specification.



Figure 10 Reflectance of Dichroics Old and New (PerkinElmer, 2018)

Build times are tested from reverse engineering current bought in assemblies to enable labour hours to be costed and added to the insourcing saving.

Affected Assemblies

L1860290 ('0290') - Upper dichroic assembly

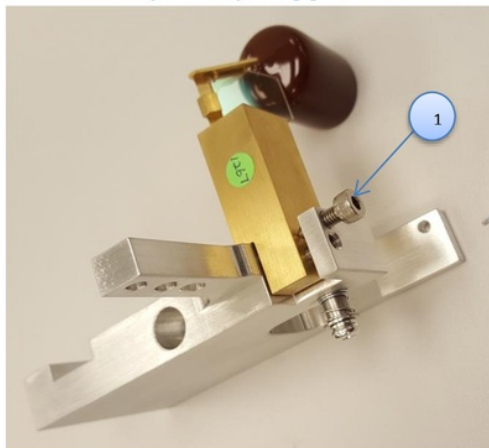


Figure 11 – Subassembly 0290 (PerkinElmer, 2018)

The dichroic mirror used in this assembly is featured in the Figure 8. The purpose of this assembly is to change the angle of the upper dichroic mirror using the adjustment screw (1, in Fig12). Adjustment only occurs during testing in order to even out the energy levels found across the 16 detector points. This adjustment process achieves uniformity of the detector points for the machine.

This assembly is fitted within the interior frame of the machine and rests above the magnification system

L1860292 ('0292') - Transmittance/Reflectance assembly

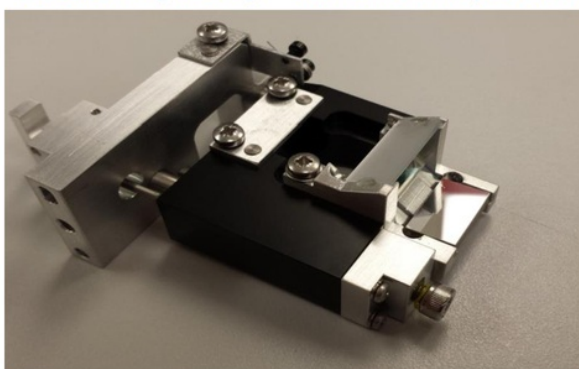


Figure 12 - 0292 Subassembly (PerkinElmer, 2018)

This attaches onto the spotlight within a separate housing. The purpose of it is to extend and retract a series of three mirrors inside a small cavity, which is assembled through rails which allow the mirrors to move in and out of action according to the mode in which the customer intends to use, IR or visible light.

L1860309 ('0309') - Junior Transmittance/Reflectance Assembly

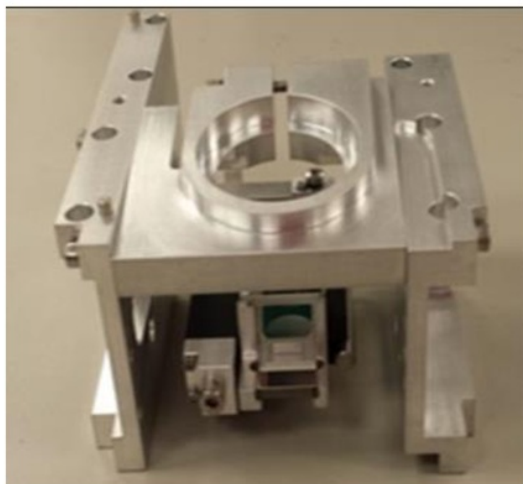


Figure 13 - Subassembly 0309 (PerkinElmer, 2018)

This assembly is largely a mounting system to support the working optics and attach them to the instrument with the multitude of mounting holes along the walls. The 0309 houses the 0292 underneath as shown in figure 13 encased in three aluminium machined walls joined together using metal dowels and superglue. A key feature of optical functionality machined into the housing is the large circular cavity on its roof. This gives space for the light to pass through it.

L1860284 ('0284') Z Fold Mount and Transmittance and Reflectance Assembly

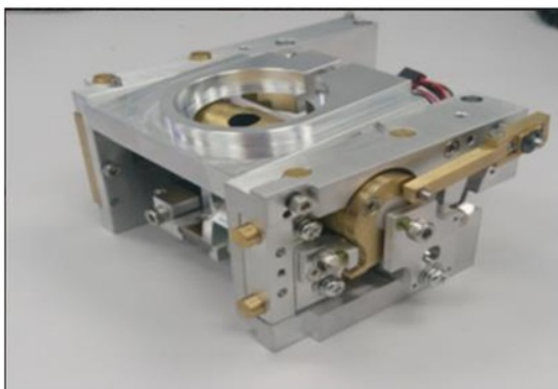


Figure 14 0284 Assembly (PerkinElmer, 2018)

This is the magnification system unit. This consists of a 0309, plus extra arm mechanisms and electronics required to rotate the z fold tube in the housing 90 degrees along its horizontal axis. This movement engages and disengages the tube thus turning magnification on and off.

Costings

The costings are calculated per build from the one supplier, this does create a vulnerability in that the project is based on the quotes supplied. Another uncertainty not explained in the following costs per subassembly is Brexit. Llantrisant's business is operated out of the UK within the EU which will have a knock-on influence on every instrument or accessory shipped out of the plant and on all imported parts shipped to the plant. Fluctuations in the exchange rate of the dollar, pound and euro must also be factored.

The tables below are made to illustrate the reasoning behind insourcing in a clear concise manner. As shown, the costs for the jigs and fixtures is not yet included. The savings found will give structure to the spending allowance on the project. The labour rate will also not remain the same over time, however these details were correct at the time of writing. The demand quantity is quite stable year on year as the Spotlight is a core instrument in the Health Sciences department.

Table 1 – Costings 0290 Subassembly (PerkinElmer, 2018)

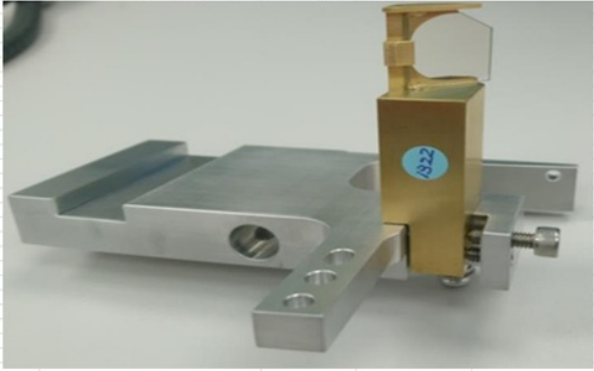
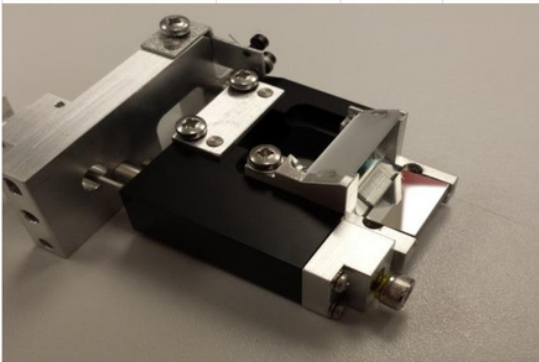
Current US \$ Rate		Current Euro Rate €		
\$1.31		1.12 €		
External Vendor Costs :		GBP £	USD \$	Euro €
A	PO Price	£84.50	\$110.70	94.64 €
	Free Issue Parts Total	£0.00	\$0.00	0.00 €
	Transportation Inbound	£0.00	\$0.00	0.00 €
	Transportation Outbound	£0.00	\$0.00	0.00 €
	Additional Dichroic Purchase cost	£27.82	\$36.44	31.16 €
	Labour Rework Dichroic cost	£54.61	\$71.54	61.16 €
	Total A (Vendor supply cost)	£166.93	\$218.68	186.96 €
Insourced Costs :		Analysis	USD \$	Euro \$
B	Material	£97.68	\$127.96	109.40 €
	Material Burden	£5.93	\$7.77	6.64 €
	Transportation Inbound	£0.00	\$0.00	0.00 €
	Labour (0.625 hour build)	£29.81	\$39.05	33.39 €
	Jigs & Fixtures	£0.00	\$0.00	0.00 €
	Total B (Insourced supply cost)	£133.42	\$174.78	149.43 €
2016 annual demand QTY		182		
Annual Vendor Cost		£30,381.26	\$39,799.45	34,027.01 €
Cost difference per unit		£33.51	\$43.90	37.53 €
Total annual Insourced Cost		£24,282.12	\$31,809.57	27,195.97 €
Annual Insourced Savings £		£6,099.14		
Annual Insourced Savings \$ US		\$7,989.88		
Annual Insourced Savings EU €		6,831.04 €		
L1860290 VIS/IR MIRROR ASSEMBLY				Project Savings
				£6,099.14
				\$7,989.88
				6,831.04 €

Table 2 – Costings L1860292 Subassembly (PerkinElmer, 2018)

Current US \$ Rate		Current Euro Rate €			
\$1.31		1.12 €			
External Vendor Costs :		GBP £	USD \$	Euro €	Comments
PO Price		£128.06	\$167.76	143.43 €	
Free Issue Parts Total			\$0.00	0.00 €	
Transportation Inbound			\$0.00	0.00 €	
Transportation Outbound			\$0.00	0.00 €	
Additional Dichroic Purchase cost		£81.78	\$107.13	91.59 €	
Labour Rework Dichroic cost		£35.77	\$46.86	40.06 €	
Total A (Vendor supply cost)		£245.61	\$321.75	275.08 €	
Insource Costs :		Analysis	USD \$	Euro \$	Comments
Material		£156.12	\$204.52	174.85 €	
Material Burden		£11.17	\$14.63	12.51 €	
Transportation Inbound		£0.00	\$0.00	0.00 €	
Labour (0.625 hour build)		£23.85	\$31.24	26.71 €	Technician rate - \$47.70 per hour
Jigs & Fixtures		£0.00	\$0.00	0.00 €	
Total B (Insource supply cost)		£191.14	\$250.39	214.08 €	
		Status			
2016 annual demand QTY		145			100% Costings completion Sample materials on order 01/05/18
Annual Vendor Cost		£35,613.45	\$46,653.62	39,887.06 €	
Cost difference per unit		£54.47	\$71.36	61.01 €	
Total annual Insource Cost		£27,715.30	\$36,307.04	31,041.14 €	
Annual Insourced Savings £		£7,898.15			
Annual Insourced Savings \$ US		\$10,346.58			
Annual Insourced Savings EU €		8,845.93 €			
L1860292 SPOTLIGHT TRANS/REFL ASSY		Project Savings			
		£7,898.15			
		\$10,346.58			
		8,845.93 €			

Chapter 3: Z Fold Investigation

Optical Coatings for Z fold Tube

Optical paint within the Z fold tube is layered inside to ensure that scattered light produced upon reflecting dust particles does not go astray and alter the functionality of optical system that is houses.

The internal geometry is complex yet precise. The original specifications for this component were unknown and any records of reasoning to its features lost, therefore the task was expanded to a short analysis of part drawings. This brass component had no additional records or valuable notes to describe the stray light specification or the means of adhering the paint into the tube.

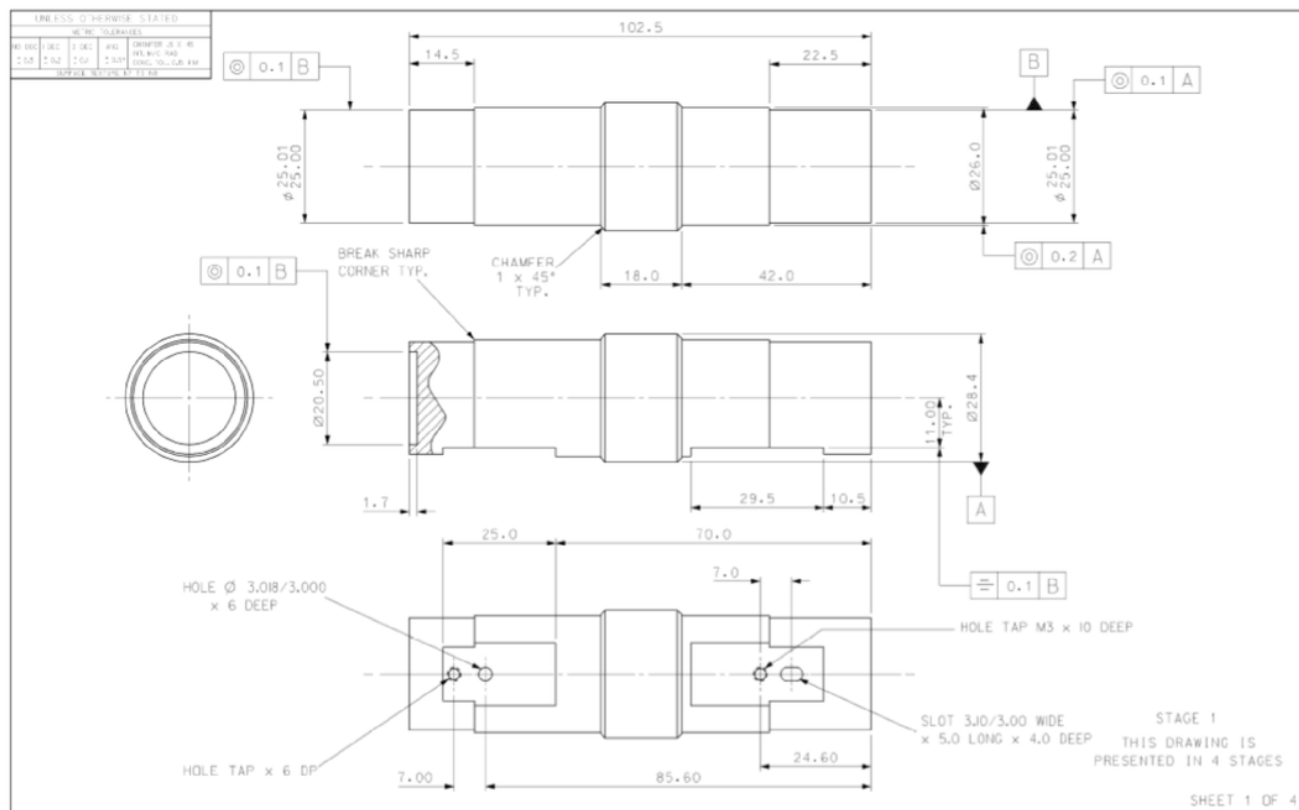


Figure 15 Drawing of Z fold (PerkinElmer, 2018)

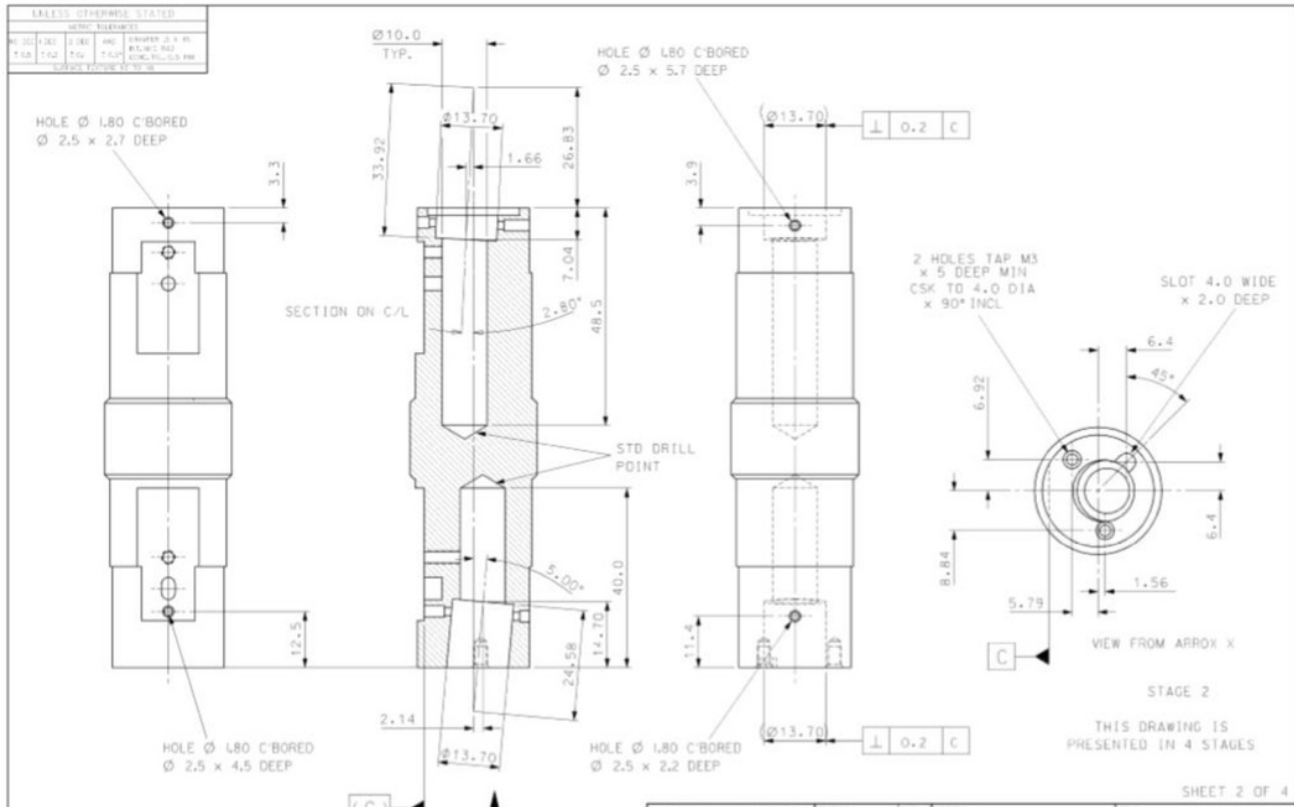


Figure 16 Drawing 2 of Z fold (PerkinElmer, 2018)

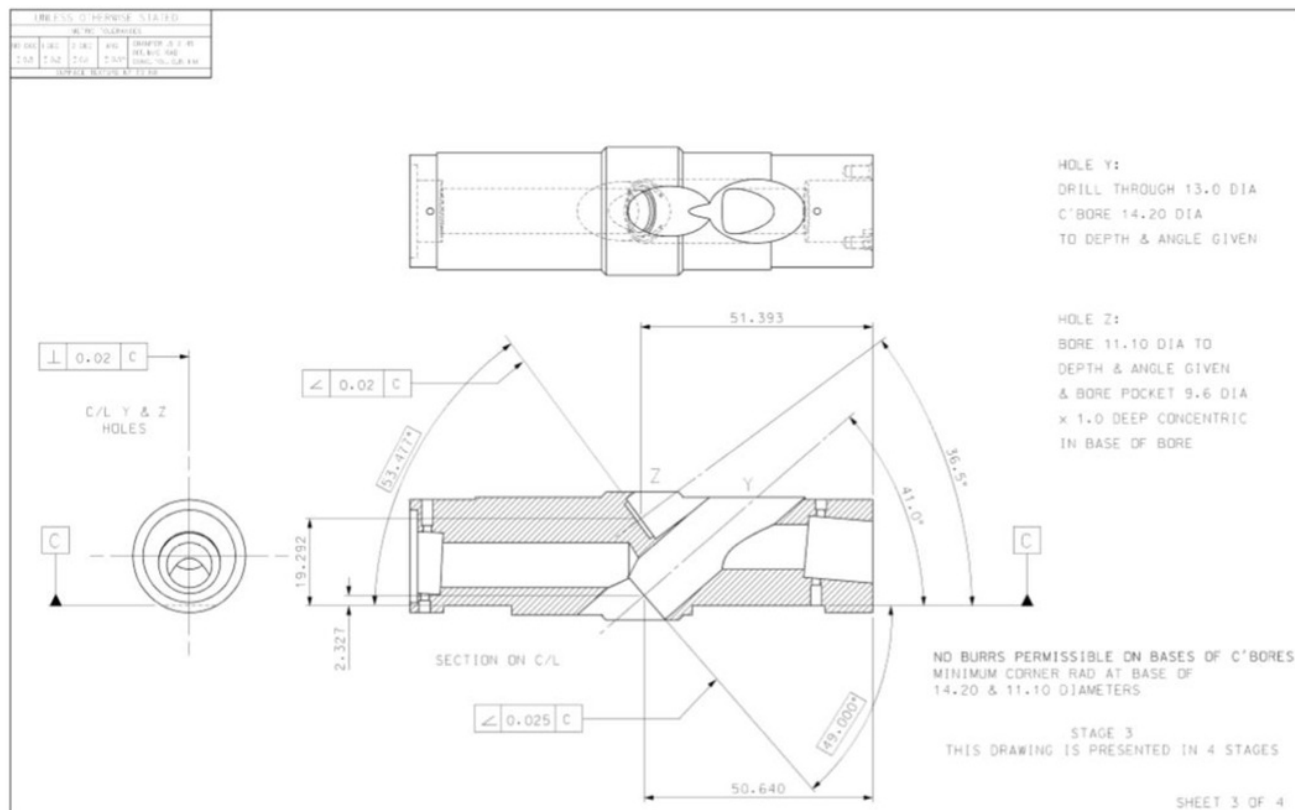


Figure 17 Drawing 3 of Z fold (PerkinElmer, 2018)

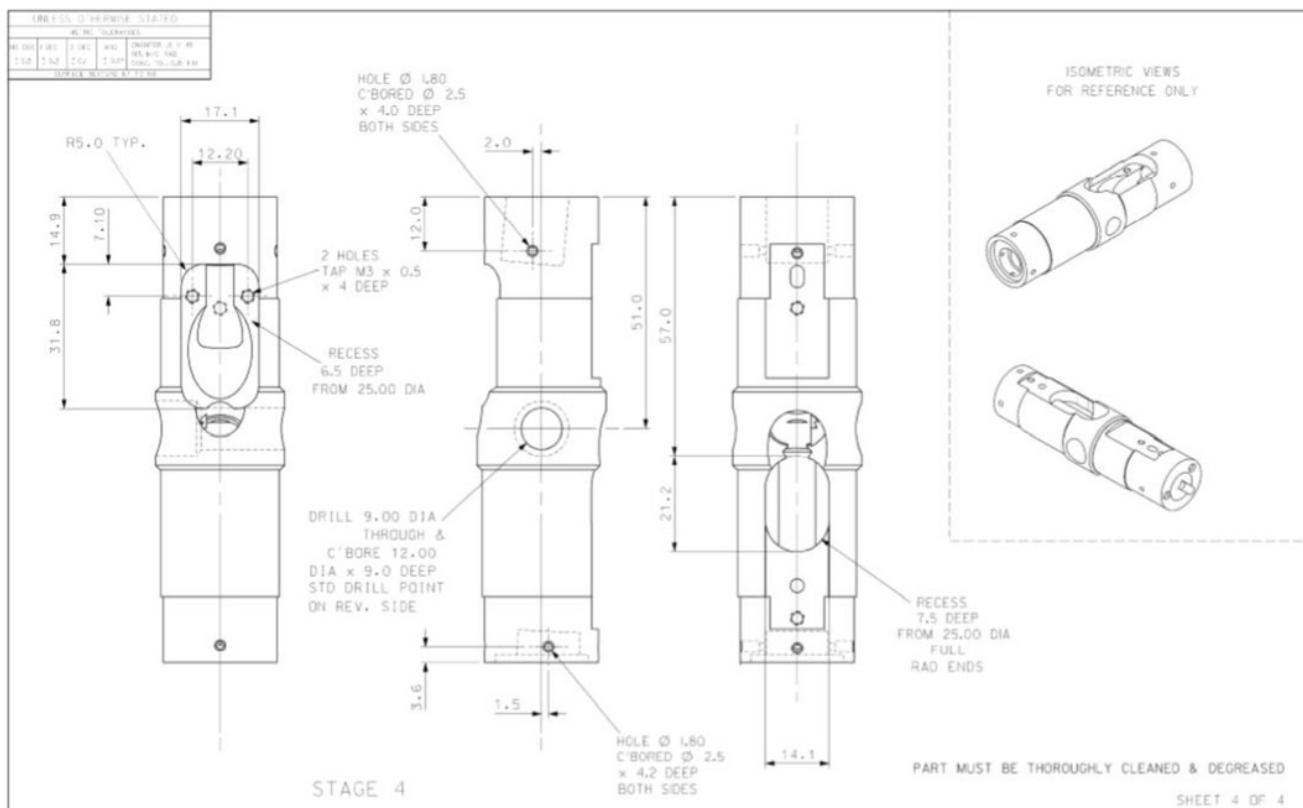


Figure 19 Drawing 4 of Z fold (PerkinElmer, 2018)

Below, figure 17, is a crude representation of the light through the system. This shows how precisely directed the beam must be by the instrument to read a sample in transmittance or reflectance mode.

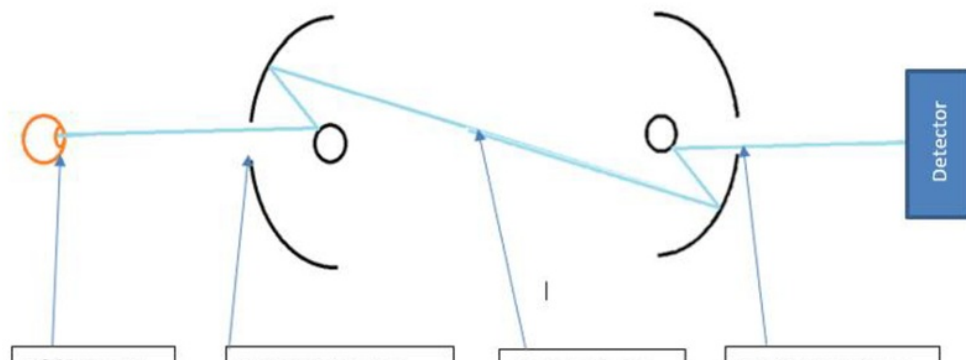


Figure 18 Optical System Spotlight (PerkinElmer, 2018)

Using a quickly made rig using R&D parts in a laboratory, the affects of light positioning were found through using the effects on the spot quality of a laser.

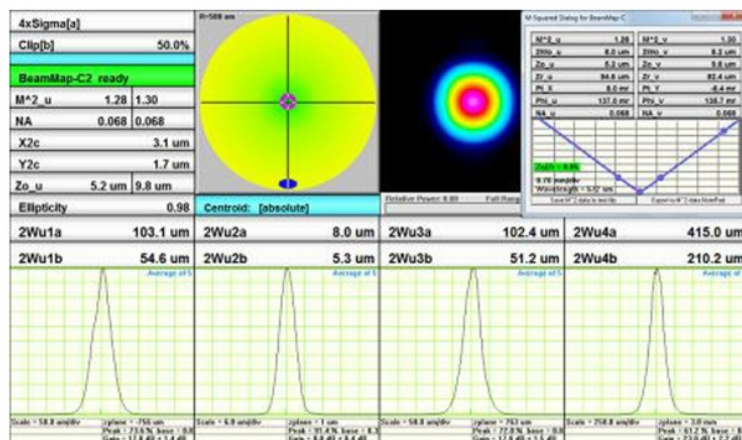


Figure 20 Using BeamMap2 Software

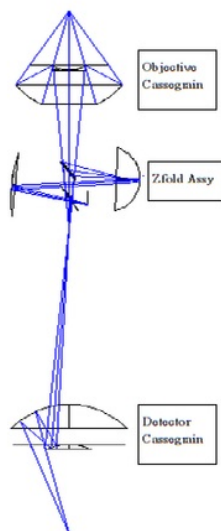


Figure 21 Instrument Light Path

Figure 20 above shows the optical path in the optical modelling software Zemax. The blue lines are accurate theoretical representations of light within the system.

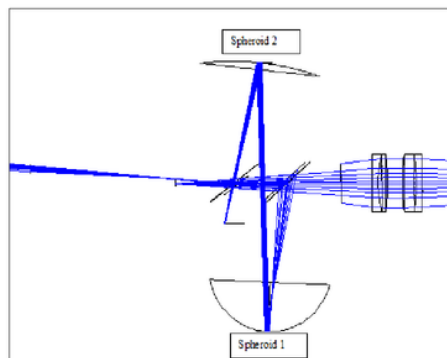


Figure 22 Zemax of an older model of alignment jig (PerkinElmer, 2000)

The beam must emerge from the Z fold in the correct direction so that it passes down the side of the detector cassegrain without vignetting. The object of the alignment jig is to allow the assembly of the Z fold such that the output beam is correctly focused and emerges along the correct path. To adjust the beam, two spheroids must be displaced and adjusted within the z fold tube during the bonding process. The only references available for determining success are determining matching locations between the optics inside the tube and the location of the spot in the X,Y and Z directions.

Flat mirror bonding is the easiest task in the alignment process. The interior cavities of the tubes allow for the correct placement of the mirror due to geometric features alone. Although there is no chance for adjustment once the glue is placed and the rework costs would consist of purchasing a new flat mirror as the incorrectly placed one would have to be destroyed in order to remove it. Therefore, no glue must be placed on the base of the mirror directly adhering to the tube. Changes in glue depth could have a great impact on the functionality of the system by slightly offsetting the direction of light from an angle generated by a spot of glue underneath. Gluing flats would have to be done with a vacuum pump system, this would make certain that the fragile and valuable parts are handled with care and without creating damage. A pump with the ends holding the optical face against its mount can keep it where required allowing a technician to carefully disperse glue on the edges for mounting. Gluing optics instead of using mechanical fixings reduces cost and can allow existing components to be amalgamated and positioned manually.

A choice in glue can be difficult to make for optical bonding as it must be thin enough to not affect the optics despite using best assembling practice. A Milbond adhesive system is an elastomeric-epoxy adhesive which is used for glass to metal bonding applications. Its layer thickness is 0.38mm. The downside to using this is that it has a short shelf life. As not many Z folds are produced a year, the minimum order requirement would accrue too much waste.

Critical appraisal of results of investigation

As results were inconclusive due to the lack of tools to complete research, without creating a jig, it is still a possibility to successfully understand and operate a jig shipped in from the current manufacturer of the parts.

Conclusions

From specialist discussions, personal insight I conclude that this project had no promise initially due to the steep learning curve required to undertake R&D work for a company as an undergraduate. The lack of promise continued through as the company was not willing to purchase optical modelling software for the

purpose of creating a jig. This means that all work carried out is not accurate nor reliable and naturally stunted the project from the beginning.

A company who wishes to investigate R&D work must evaluate their priorities as a manufacturing site and work collaboratively with the active R&D department. This requires resources, time and knowledge. The decision PerkinElmer made to terminate the R&D department back in 2000 and move it to the US has had a devastating impact on the day to day actions of the manufacturing site. The most fundamental knowledge was wrongly removed from the business which has wasted time and money for all engineering activities. This project has only surfaced due to this wrongdoing.

Recommended further work

A course in Optical Engineering and training for Zemax optical modelling software would have healthily supplemented the work. Running a Zemax analysis on glue thicknesses on the optical system would be interesting and would provide limits and a richer specification. Using robotics and AI for an alignment system would be a great route to take if the required number of parts to be aligned would be greater. There are possibilities available to make an affordable robotic optical alignment system, however that could be towards a master's degree continuing from this project.

Inventing a physical jig and running through a vigorous testing plan for PerkinElmer is still the goal, working concurrently with installing and using another manufacturers rig.

Works Cited

Davidson, M. W., 2003. *Fluorescence Microscopy*. [Online]

Available at: <https://micro.magnet.fsu.edu/primer/techniques/fluorescence/fluorescenceintro.html>
[Accessed 25 June 2018].

Gallagher, T. A. & Nemeth, A. J., 2008. An Introduction to the Fourier Transform: Relationship to MRI. *American Journal of Roentgenology*, 10.2214(AJR.07.2874), pp. 1396 - 1405.

JF, J., 2002. *A student's guide to Fourier transforms with applications in physics and engineering*. 2nd ed. Cambridge: Cambridge University Press.

PerkinElmer Inc, 2013. *FT-IR, NIR Microscopy and Imaging*. [Online]

Available at:

http://www.newproject srl.com/docs/Strumentazione%20analitica/Spettroscopia%20Molecolare/CHEIM MSPO/Data%20Sheet/DS_Spotlight%20200_400.pdf

[Accessed 1 July 2018].

PerkinElmer, 2013. *FT-IR, NIR Microscopy and Imaging*. [Online]

[Accessed July 2018].

PerkinElmer, 2013. *Spotlight Family - Brochure*. [Online]

Available at: http://www.perkinelmer.co.uk/lab-solutions/resources/docs/BRO_Spotlight_Family.pdf

[Accessed 26 June 2018].

PerkinElmer, 2018. *Internally Sourced*, s.l.: s.n.

PerkinElmer, 2018. *Our History*. [Online]

Available at:

http://www.perkinelmer.co.uk/AboutUs/timeline_us.htm?_ga=2.5735734.442418475.1535464367-517848220.1534233505

[Accessed 25 June 2018].

PerkinElmer, 2018. *Spotlight 400N FT-NIR Imaging System*. [Online]

Available at: <http://www.perkinelmer.co.uk/product/spotlight-400n-std-front-nir-tgs-us-l1860121>

[Accessed 26 June 2018].

Phoenix Electroformed Products Inc, 2018. *Cold Shields and IR Radiation shields*. [Online]

Available at: <http://www.phoenixelectroforms.com/coldshields.html>

[Accessed 1 July 2018].

Suzanne McFarlane, G. W., 2009. *Spotlight - IR Microscopy and Imaging*. s.l.:s.n.

Tokmakoff, A., 2003. *Introduction to Spectroscopy*. [Online]

Available at: <http://web.mit.edu/5.33/www/lec/spec1.pdf>

[Accessed 25 June 2018].

Vision Engineering, 2015. *History of the microscope*. [Online]

Available at: <http://www.visioneng.com/resources/history-of-the-microscope>

[Accessed 25 June 2018].

Wang, S. Z. C. A. M. D. C. G. M. a. J. Z., 2016. Optomechanical Design for Precision Lens Positioning and Mounting. *Optics and Photonics Journal*, 6(8), pp. 1-7.

Wita, G. N., 2014. *Microsoft PowerPoint - Spotlight pb4 frontier_4_UK.pptx*, Shelton: PerkinElmer Inc.

Zandi, B. & Wijewarnasuriya, D. V. a. P., 2009. *Modeling Mercury Cadmium Telluride Photodiodes*, Maryland: U.S. Army Research Laboratory.