Investigating the Working Distances of the Questar QM-1SZ Tele-Microscopes

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1 Abstract

This report is a continuation of the report entitled Investigating Contrast, Resolution and Field-of-View (FoV) of the Questar QM-1SZ Tele-Microscope by J. A. Hodson[1]. His report looked to measure the Resolution, Contrast and FoV of the two tele-microscopes with serial numbers QM110541SZ and QM110542SZ (QM-41 and QM-42) at distances of 65cm and 1.4m. This investigation will look into the working distance of these two tele-microscopes as well as the ones with serial numbers QM110540SZ and QM110543SZ (QM-40 and QM-43) which are advertised to have a much longer working distance at the cost of resolution. Measurements will be taken of the resolution and FoV of the QM-40 and QM-41 at their nearest focus, 1.2m and at their farthest focus. The working distance stated in the specifications for the QM-41 and QM-42 was from 560mm to 1520mm[2]. The working distance for the QM-40 and QM-43 was from 914mm (3 feet) to infinity[3]. However, the effective working distance from the front plate of the tele-microscopes was found to be 621mm to 1370mm for the QM-41 and QM-42. For the QM-40 and QM-43, a value of 1036mm to infinity was found.

An analysis of the capabilities of a custom built adjustable stand for the tele-microscopes will also be included. As well as an evaluation of the performance of these tele-microscopes as a referencing tool in the Dr G Scott experiment[4].

2 Motivation

Following J. A. Hodson's investigation into the QM-41 and QM-42 tele-microscopes in which he studied the resolution and field of view at 65cm and 1.4m, he was unable to form an image in zoom 1 at 1.4m. This shows that the target was outside the working distance for this zoom but within the working distance of zooms 2-5. This in part inspired the need to study the working distances for all 5 zooms on the tele-microscope. Furthermore, as he mentioned in his report 2 of the tele-microscopes (QM-40 and QM-43) were sent away to be modified to work at distances greater than 3m. Now that they have returned the working distance of these tele-microscopes and the resolution at these limits will also be tested. However, as the QM-40 and QM-43 have a working distance that extends to infinity measurements at its farthest focal point cannot be taken. Therefore the far focus measurement will be taken at 10m from the front plate of the tele-microscope to measure the resolution and FoV at a far distance that will be further than the tele-microscope will be used for most experimental setups. Finally, to compare the resolution and FoV of both tele-microscopes at the same distance measurements will be taken at 1.2m as it is within the working distance for both models. This will give any user of the tele-microscope the full range of its capabilities in a range of resolution and working distance so they can decide on the setup that best suits their needs for the experiment. A further description for these tests can be found in the initial report of the QM-41 and QM-42.[1]

3 Method

3.1 Setup

The method used for this investigation was largely based upon the method used in J. A. Hodson's report[1]. Where the method needed to be edited to accommodate the differences between the investigations as little change as possible was made to maintain consistency in the results. Firstly the tele-microscope was mounted to a fixed stand pointed at the target. A custom adjustable mount has since been manufactured for using the QM1-SZ's allowing adjustment of the Roll, Pitch and Yaw of the tele-microscopes. This had to be custom-built to accommodate the imperial screw threads in the bottom of the QM1-SZ's allowing it to attach to a mount. However, when taking measurements this was not yet available.

Behind the target was a green LED light source with an inbuilt diffuser to create a uniform back-light of the target. The target was placed on a magnetic clamp stand to allow ease of motion when necessary and the ability to secure it in place when taking measurements. The distance from the target to the tele-microscope was taken to be the distance from the side of the target closest to the tele-microscope to the front panel of the QM1-SZ.

In the initial report[1] it was stated that an Allied Vision Stingray FireWire.b Camera, model F-033B camera was used. However, after taking some initial measurements with this camera it was often found that the limiting factor for resolution and FoV was the camera itself, not the tele-microscope that was being tested. Therefore, this was replaced with an Allied Vision Manta Camera, model G-235B as it had a larger chip with higher pixel density. Increasing the maximum FoV and causing fewer images' resolution to be limited by the number of pixels available. This setup can be seen in Figure 1.

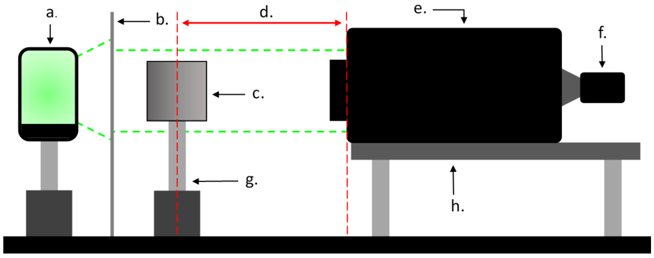

Figure 1: Setup used to collect experimental results.
a. LED Light Source used to back-light the target.
b. Diffuser used to make the back-light beam uniform.
c. The target, either a ruler to measure the Fov or USAF Resolution Test Target.
d. Distance to target from the front plate of QM1-SZ.
e. The QM1-SZ tele-microscope.
f. Allied Vision Manta Camera, model G-235B giving a live view of the target.
g. Magnetic clamp stand to move and secure the target.
h. An adjustable stand not used when taking these measurements. This is elaborated on in Section 6.4.

3.2 *Measuring Resolution*

As elaborated upon in the report[1], to measure the resolution of images taken a 1951 USAF resolution test target, as seen in Figure 2, was used. When taking measurements at the nearest or farthest focus the target was physically moved into a position of focus. When taking measurements at a fixed distance the target was placed at that position and pull focus to the target. At each position, all 5 zoom setting were tested for contrast and FoV. The results of the contrast or the pixel count of the image were used to determine the resolution of the image, depending on which was the limiting factor. When finding the FoV for each position the test target was swapped for a ruler with increments of 0.5mm and front-lit with a torch to measure the FoV with an error of ±0.25mm.

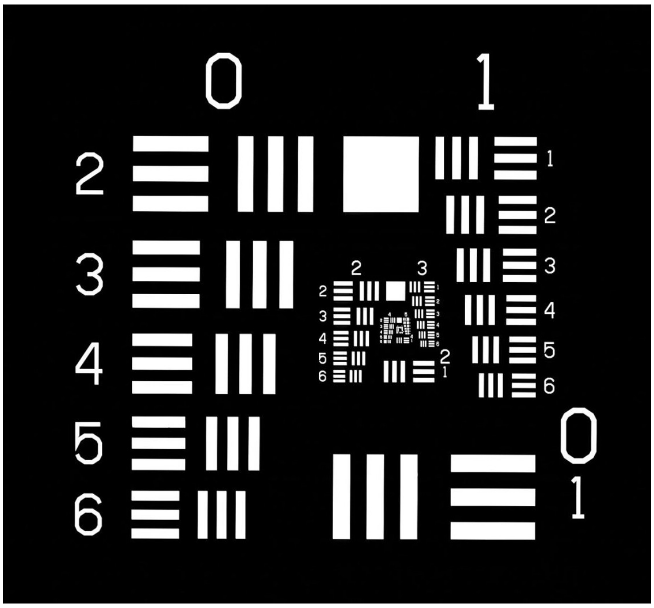

Figure 2: 1951 USAF resolution test target[5]

With 2 tele-microscopes (QM-40 and QM-41), 3 locations (10m/Farthest, 1.2m and Nearest) and 5 zooms this totals 30 images to study to find the resolution and a further 30 to measure the FoV. The resolution of an image was either limited by the pixel count of the G-235B camera or the contrast of the image as determined by the tele-microscope. If the pixel count of the camera was the limiting factor then using a camera with a higher pixel density would give the user a higher resolution than could be measured in this setup. The camera being used has a pixel size of 5.86×5.86microm on a sensor of size 11.3×7.0mm. A minimum pixel count for each Element (3 bright stripes and 2 dark stripes) was set as 10 pixels, 2 per stripe. This number was chosen as 10 pixels is easy to identify and resolve as it only has 2 options for patterns produced by pixel alignment as seen in Figure 3.

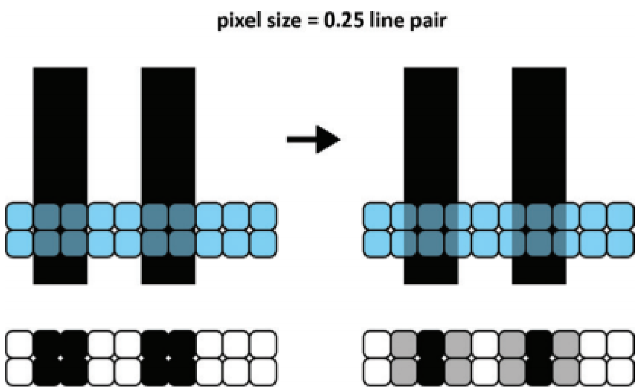

Figure 3: Demonstration of the patterns produced by a 10 pixel resolution limit

If the contrast of the image is the limiting factor then a metric to measure the contrast of an element was needed. For this, the same method as J. A. Hodson's report[1] was used, the Modulation Transfer Function (MTF). As described in the report the MTF of an Element gives a value between 0 and 1 that describes its contrast. If a line-out is taken over an element then the MTF of that element is given as Equation 1 where I_{max} and I_{min} are the maximum and minimum intensity of the line-out respectively. A high value for the MTF describes a crisp image and a low value describes an image with low contrast and therefore a low resolution.

$$M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{1}$$

After measuring the MTF of several elements in several images a minimum MTF of 0.2 was settled on as elements with an MTF $\geqslant 0.2$ appear to be much higher quality and much more resolvable than elements below this threshold. In Figure 4 Elements 2 and 3 have a MTF above 0.2 and Elements 4 and 5 have a MTF bellow 0.2. It was believed that this image demonstrated a significant difference between the resolvability above an MTF of 0.2 compared to below it. However, occasionally the horizontal and vertical resolution will be slightly different. Therefore an element will only be classed as resolvable if both the horizontal and vertical component has an MTF $\geqslant 0.2$. If an element is resolvable the resolution of that image can be calculated by using the Equation 2 or by looking up in Table 9.

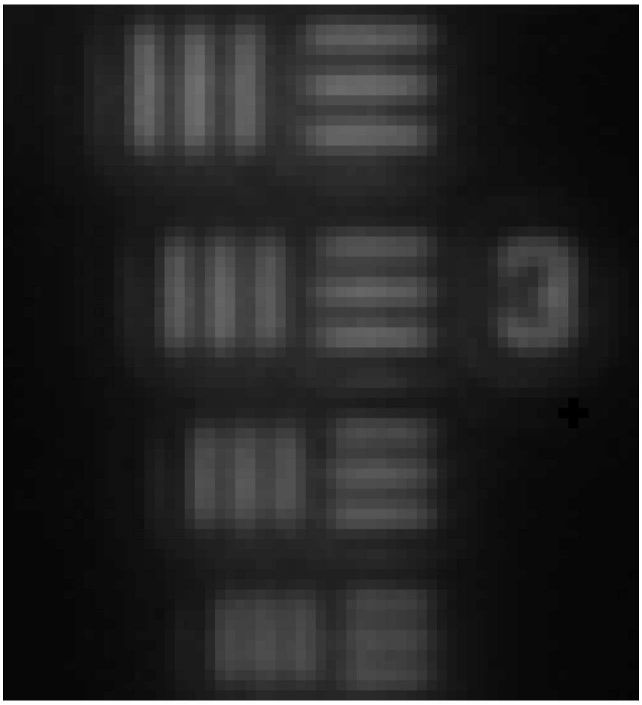

Figure 4: Demonstration of the 0.2 MTF resolution limit. Shown is Group 7 from Zoom 4, Nearest Focus of the QM-41.

$$Resolution(lp/\text{mm}) = 2^{Group + \frac{Element-1}{6}} \tag{2}$$

Using these two characteristics of a limit of 10 pixels per Element and an MTF $\geqslant 0.2$ both horizontally and vertically the resolution and FoV of the 30 situations being studied in this investigation can be calculated.

3.3 Measuring Field-of-View

To measure the FoV of an image a ruler with increments of 0.5mm was front-lit. This was then used to observe the FoV with an error of ±0.25mm. In Figure 5 can be observed a 6.5mm±0.25mm Field-of-View obtained with the QM110541SZ at the nearest focus of Zoom 2.

However, it is possible that the image produced by the tele-microscope is larger than the sensor of the camera used and therefore the FoV is limited by the size of the sensor used on the Allied Vision Manta Camera, model G-235B. This camera has a sensor of size 11.3mm × 7.0mm. If a camera with a larger sensor was used, a potentially larger image would be visible creating a larger FoV. This is the case for all images taken with both tele-microscopes.

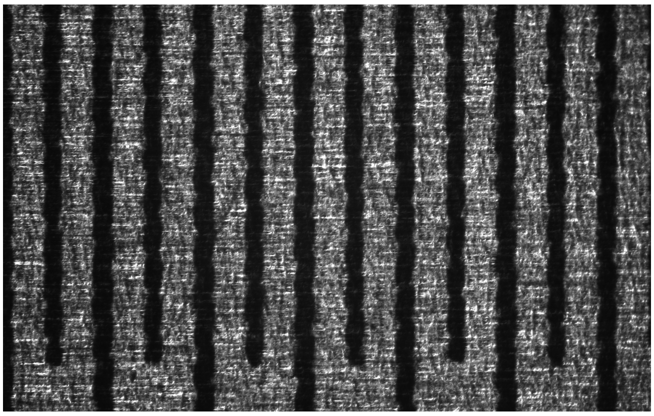

Figure 5: Field-of-View measurement taken with the QM-41 at nearest focus o Zoom 2

4 Results of the QM110541SZ at working limits

4.1 Introduction

Here the experimental results of the short-range high-resolution tele-microscopes will be covered. The results for these tele-microscopes at 65cm and 1.4m has been evaluated by J. A. Hodson in his report[1]. Here the working distance and the resolution and Fov at the limits of this working distance will be studied.

Zoom	Distance (mm)	Resolution (lp/mm)	FoV (mm)
1	591	40.3	12.00
2	607	71.8	6.50
3	616	114.0	4.00
4	618	161.3	2.00
5	621	161.3	2.25

Table 1: QM110541SZ Nearest Focus

4.2 Nearest Focus

When measuring the resolution at the nearest focus for the QM-41 the absolute closest an image could focus was 591mm from the front plate on zoom 1. This gives allows the user to resolve up to 40.3 lp/mm with an FoV of 12mm. Zoom 5 focuses at 621mm and can resolve 161.3 lp/mm with a FoV of 2.25mm.

Table 1 displays the nearest focus distance, resolution and FoV for all zooms. The resolution for zoom 1, 2 and 3 are limited by the 10 Pixel limit so using a camera with a higher pixel density would potentially deliver better results. Figure 6 shows how the modulation changes with the resolution for the 5 zooms vertically. The highest resolution data point for each zoom is the resolution of the element at the 10-pixel limit.

4.3 Furthest Focus

When measuring the resolution at the furthest focus for the QM-41 the absolute furthest an image could focus was 1583mm from the front plate on zoom 5. This allows the user to resolve up to 50.8 lp/mm with an FoV of 6mm. Zoom 1 focuses at 1370mm and can resolve 16 lp/mm with a FoV of 29mm.

Table 2 displays the furthest focus distance, resolution and FoV for all zooms. The resolution for zoom 1 is limited by the 10 Pixel limit so using a camera with a higher pixel density would potentially deliver better results. Figure 7 shows how the modulation changes with the resolution for the 5 zooms vertically. The highest resolution data point for each zoom is the resolution of the element in that image at the 10-pixel limit.

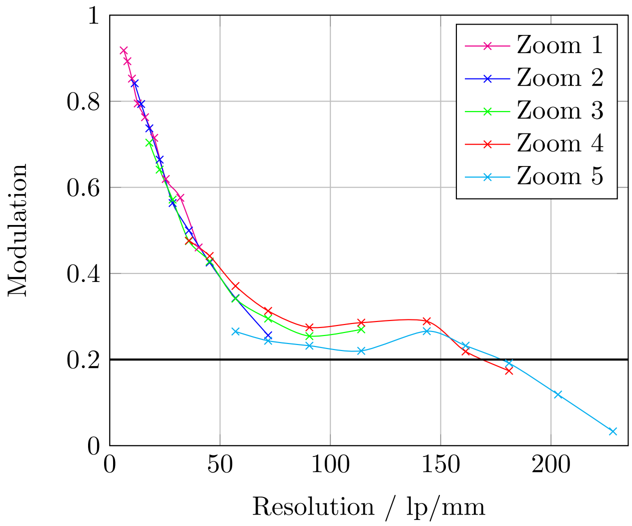

Figure 6: QM-41 Nearest Focus Vertical Modulation

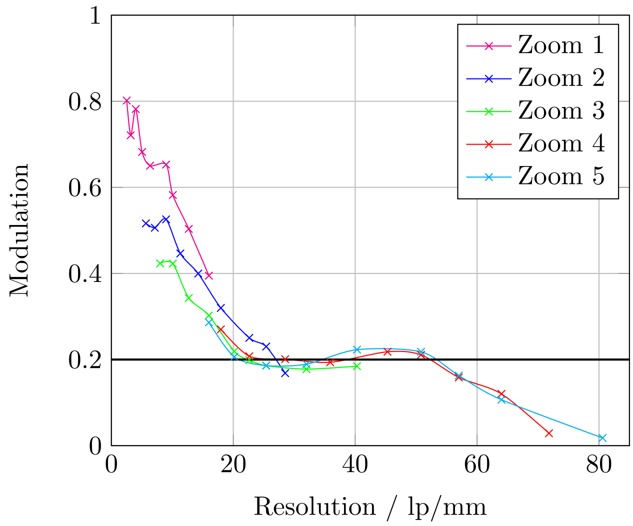

Figure 7: QM-41 Furthest Focus Vertical Modulation

Zoom	Distance (mm)	Resolution (lp/mm)	FoV (mm)
1	1370	16.00	29.00
2	1482	25.40	17.25
3	1536	20.16	11.00
4	1567	50.80	7.75
5	1583	50.80	6.00

Table 2: QM110541SZ Farthest Focus

Zoom	Distance (mm)	Resolution (lp/mm)	FoV (mm)
1	916	22.63	21.50
2	980	16.00	12.75
3	1010	28.51	8.25
4	1027	28.51	5.75
5	1036	28.51	4.50

Table 3: QM110540SZ Nearest Focus

5 Results of the QM110540SZ at working limits

5.1 Introduction

This will cover the experimental results of the long-range low-resolution tele-microscopes. These tele-microscopes have not yet been studied at all so this will give fresh data on what they can do. Here the working distance and the resolution at the limits of this working distance will be studied.

5.2 Nearest Focus

When measuring the resolution at the nearest focus for the QM-40 the absolute closest an image could focus was 916mm from the front plate on zoom 1. This allows the user to resolve up to 22.63 lp/mm with a FoV of 21.5mm. Zoom 5 focuses at 1036mm and can resolve 28.51 lp/mm with a FoV of 4.5mm.

Table 3 displays the nearest focus distance, resolution and FoV for all zooms. The resolution for zoom 1 is limited by the 10 Pixel limit so using a camera with a higher pixel density would potentially deliver better results. Figure 8 shows how the modulation changes with the resolution for the 5 zooms vertically. The highest resolution data point for each zoom is the resolution of the element at the 10-pixel limit.

5.3 Far Focus (10m)

When measuring the resolution at the far focus of 10m for the QM-40 zoom 1 was able to resolve up to 2 lp/mm with a FoV of 248mm. Zoom 5 can resolve 3.56 lp/mm with a FoV of 47.5mm.

Table 4 displays the far focus resolution and FoV for all zooms. The resolution for zoom 1 and 2 are limited by the 10 Pixel limit so using a camera with a higher pixel density would potentially deliver better results. Figure 9 shows how the modulation changes with the resolution for the 5 zooms vertically. The highest resolution data point for each zoom is the resolution of the element at the 10-pixel limit.

Zoom	Resolution (lp/mm)	FoV (mm)
1	2.00	248.0
2	3.56	141.5
3	4.00	94.0
4	4.00	74.0
5	3.56	47.5

Table 4: QM110540SZ Far Focus (10m)

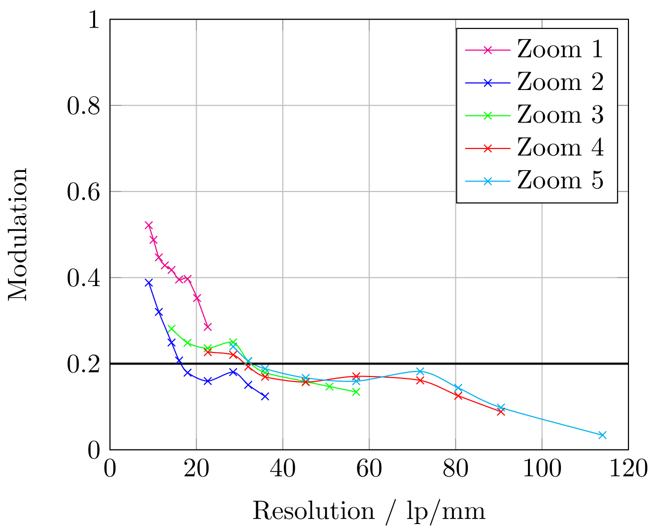

Figure 8: QM-40 Nearest Focus Vertical Modulation

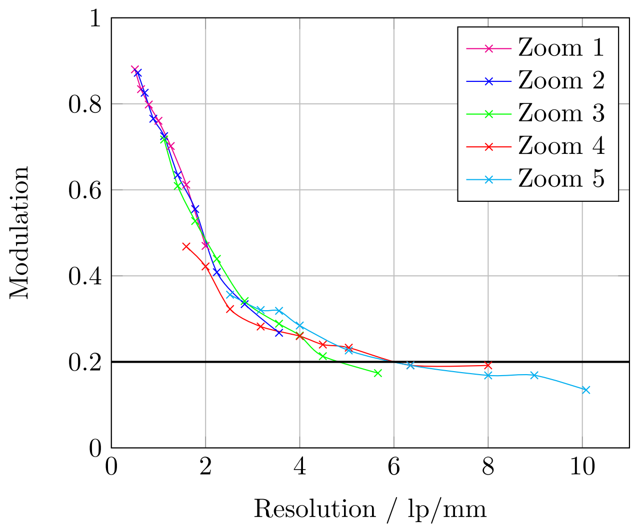

Figure 9: QM-40 Far Focus (10m) Vertical Modulation

6 Results of the QM110540SZ and the QM110541SZ at 1.2m

6.1 Introduction

Here the experimental results of the QM110540SZ and the QM110541SZ at 1.2m will be compared. This will identify how the two tele-microscopes differ at the same distance from their front plate that is well within both of their working distances for all zooms. Given the specifications for the two tele-microscopes, it is to be expected the QM110541SZ to have a higher resolution at this distance than the QM110540SZ.

6.2 QM110541SZ at 1.2m

When measuring the resolution at 1.2m for the QM-41 zoom 1 was able to resolve up to 20.16 lp/mm with a FoV of 25mm. Zoom 5 can resolve 64 lp/mm with a FoV of 4.5mm.

Table 5 displays the far focus resolution and FoV for all zooms. The resolution for zoom 1 is limited by the 10 Pixel limit so using a camera with a higher pixel density would potentially deliver better results. Figure 10 shows how the modulation changes with the resolution for the 5 zooms vertically. The highest resolution data point for each zoom is the resolution of the element at the 10-pixel limit.

Zoom	Resolution (lp/mm)	FoV (mm)
1	20.16	25.00
2	32.00	13.50
3	50.80	8.50
4	64.00	6.00
5	64.00	4.50

Table 5: QM110541SZ at 1.2m

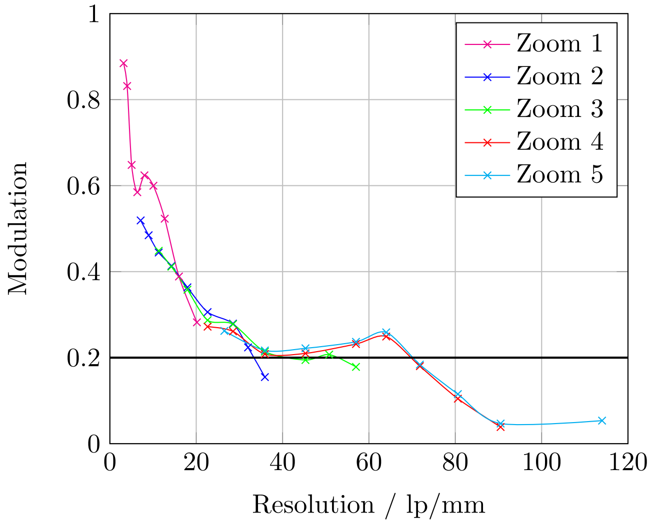

Figure 10: QM-41 1.2m Vertical Modulation

6.3 QM110540SZ at 1.2m

When measuring the resolution at 1.2m for the QM-40 zoom 1 was able to resolve up to 16 lp/mm with a FoV of 28.5mm. Zoom 5 can resolve 26.51 lp/mm with a FoV of 5.25mm.

Table 6 displays the far focus resolution and FoV for all zooms. Figure 11 shows how the modulation changes with the resolution for the 5 zooms vertically. The highest resolution data point for each zoom is the resolution of the element at the 10-pixel limit.

Zoom	Resolution (lp/mm)	FoV (mm)
1	16.00	28.50
2	12.31	15.75
3	16.00	10.00
4	14.25	6.75
5	26.51	5.25

Table 6: QM110540SZ at 1.2m

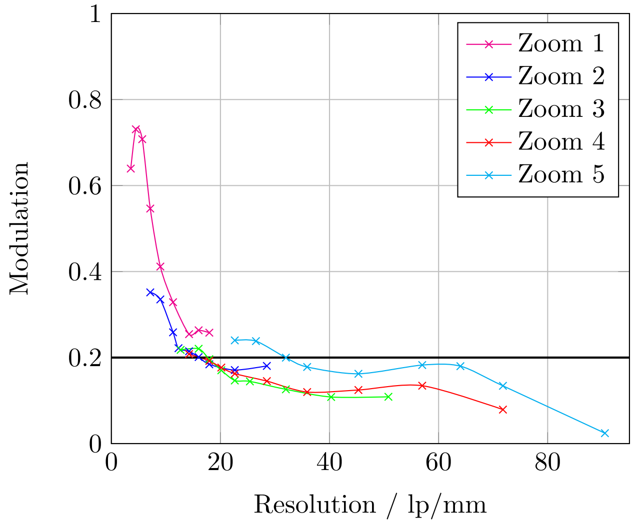

Figure 11: QM-40 1.2m Vertical Modulation

6.4 Range and capabilities of custom built adjustable stand for the QM1-SZs

The custom-built stand for the QM1-SZ tele-microscopes had not been completed when taking data for this report. However, once it had been finished a few measurements of the range of motion it offers the tele-microscope were taken. To collect this data the QM-41 was used and the target was placed at 1.2m for consistency. Figure 12 shows the QM-41 set up on the stand to take measurements.

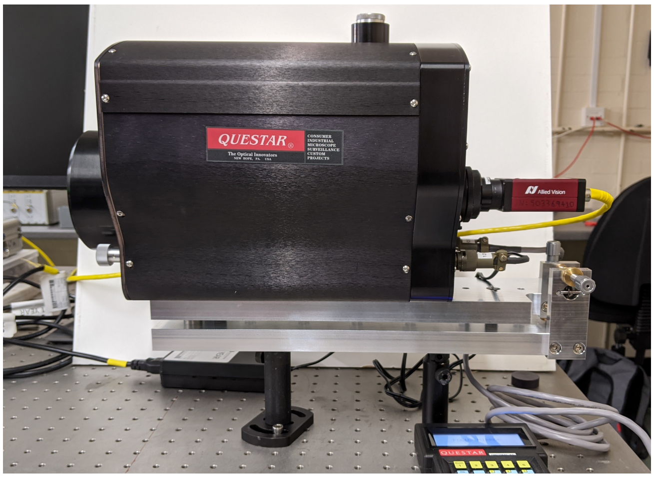

Figure 12: Setup of QM-41 on the custom stand

This stand does not offer translational motion in the x, y and z axes. It instead allows the user to change the Roll, Yaw and Pitch of the stand. These angular axes can be observed in Figure 13 and follow the right-hand convention to determine the positive direction. To measure the angular displacement first the translational displacement at a distance of 1.2m was measured. To do this a ruler was placed as the target and front-lit. Pictures were then taken at the maximum positive and maximum negative displacement for all 3 axes as well as the origin. Then the angle traversed by the stand was calculated. These results can be found in Table 7. When taking these measurements it had to be taken into account that the pivot of the stand is 39mm back from the front panel of the QM1-SZ and 111mm below the line of sight. However, this difference in the position of the pivot over distances of a meter or so made a difference of less than a hundredth of a degree.

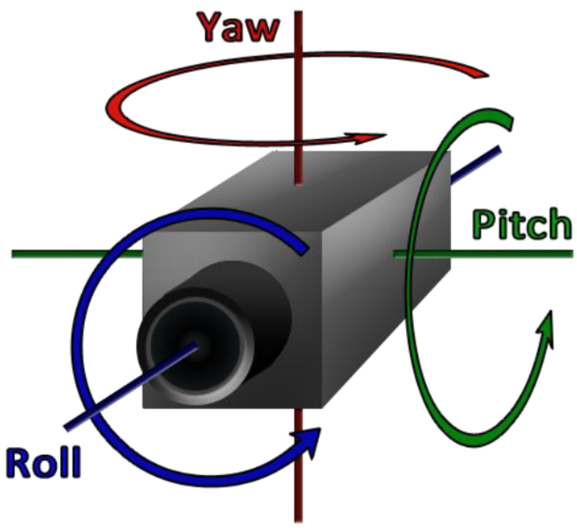

Figure 13: Yaw, Roll and Pitch[6]

Displacement	Roll	Yaw	Pitch
Positive	4.33	1.13	0.69
Negative	7.50	0.00	0.67

Table 7: Maximum angular displacement / $\theta°$

At the 1.2m distance measurements were taken these angles translate to a movement of the FoV that can be seen in Table 8. There is no translation for the Roll as this axis rotates about the line of sight so changes the angle the user is viewing but not the direction the user is looking.

Displacement	Yaw (mm)	Pitch (mm)
Positive	24.5	14.5
Negative	0.0	15.0

Table 8: Maximum translational displacement at 1.2m

The limits of the stand are determined by each other axes not being usable if one axis is overextended. The screws that push the stand in one axis can move off the bases that support them. Furthermore, the Yaw of the stand can only move in the positive direction (counter-clockwise from above) so this must be taken into account when in use. With these restrictions in mind it is not recommended using the Pitch more than 0.6° in either direction, the Yaw no more than 1° in the positive direction and the Roll no more than 4° positive and 7° negative.

7 Analysis of results

7.1 Introduction

Now that all the data needed of the working limits has been collected, resolution and FoV of both the QM-41 and the QM-40 the data can be summarised into a format that will be most useful for users to determine if these tele-microscopes will be a useful referencing tool for their experiment.

7.2 Working Limits

Here at CLF, there are four tele-microscopes from the QM1-SZ series. The QM110540SZ, QM110541SZ, QM110542SZ and the QM110543SZ (QM-40, QM-41, QM-42, QM-43). The QM-41 and the QM-42 were studied by J. A. Hodson in his report [1] where the resolution and FoV were tested at 65cm and 1.4m. Now the working distance of these tele-microscopes has been measured, their resolution and FoV at the limits of this working distance. The QM-40 and the QM-43 have not yet been studied and so the working distance of these tele-microscopes was also measured, their resolution and FoV at the limits of this working distance.

As can be seen in Section 4 it was found that for use of all 5 zoom options the tele-microscope offers, the QM-41 and QM-42 have a working distance from 621mm to 1370mm. Beyond this zoom 1 can focus as close as 591mm and zoom 5 can focus as far as 1583mm. With this setup, the best resolution that could be measured was 161.3 lp/mm at the nearest focus of zoom 5 which allows the user to resolve an object that is 6.20µm across. This position, however, gave the narrowest FoV of 2.25mm. The worst resolution measured for these tele-microscopes was 16 lp/mm at the farthest focus of zoom 1. However, this was limited by the pixel size as discussed earlier. This would allow the user to resolve an object 62.50µm across. This position also identifies the largest FoV with this tele-microscope of 29mm.

In Section 5 it was found that for use of all 5 zoom options the tele-microscope offers, the QM-40 and QM-43 have a working distance from 1036mm to ∞. Beyond this zoom 1 can focus as close as 916mm. With this setup, the best resolution that could be measured was 28.51 lp/mm at the nearest focus of zoom 5 which allows the user to resolve an object that is 35.08µm across. This position, however, gave the narrowest FoV of 4.5mm. The worst resolution measured for these tele-microscopes was 2 lp/mm at 10m in zoom 1. However, this was limited by the pixel size as discussed earlier. This would allow the user to resolve an object 0.5mm across. This position also identifies the largest FoV with this tele-microscope of 248mm.

This shows that the QM-40 and QM-43 have a much larger working distance but it is unable to resolve anything closer than a meter. The QM-41 and QM-42 has a much smaller working distance but is more useful at a close range. This also suggests that the QM-41 and QM-42 has a better resolution but this is hard to determine without comparing them at the same distance from a target.

7.3 Comparison at 1.2m

As both pairs of tele-microscopes have very different working distances and ranges of the resolution, it is quite hard to compare them to each other at their working limits. Therefore the resolution and FoV of them both at 1.2m was measured. This is a distance that is well within the working distance of all the tele-microscopes. By measuring the QM-41 and QM-42 at this distance a range of resolution was found starting at 20.16 lp/mm in zoom 1, although this was limited by pixel size as discussed before, allowing the user to resolve objects 49.60µm across. It could then resolve up to 64 lp/mm in zoom 5, allowing the user to resolve objects 15.63µm across. These zooms identifies FoV's of 25.0mm and 4.5mm respectively.

Comparatively the QM-40 and QM-43 at 1.2m a range of resolution was found starting at 16 lp/mm in zoom 1 allowing the user to resolve objects 62.5µm across. A resolution of up to 26.51 lp/mm in zoom 5could then be found, allowing the user to resolve objects 37.7µm across. These zooms identifies FoV's of 28.5mm and 5.25mm respectively.

It can now be concluded from this data that the QM-41 and QM-42 have a much higher resolution in all zooms than the QM-40 and QM-43. This simply means that using these tele-microscopes will be a matter of selecting the specific needs of an experiment and potentially to use both types in different locations for referencing due to the differences in working distance and resolution. Another interesting difference is that fact that the FoV is different between the two tele-microscopes at the same difference, suggesting a different level of magnification. Something that might be interesting to look into would be to see the differences in resolution for the same sized image on both tele-microscopes. Not at the same distance but at distances such that the same image of the target appears as the same size on the camera chip with both tele-microscopes in the same zoom. It is to be expected the QM-41 and QM-42 would still produce a higher resolution image, however.

	Group Number									
Element	-2	-1	0	1	2	3	4	5	6	7
1	0.250	0.500	1.00	2.00	4.00	8.00	16.00	32.0	64.0	128.0
2	0.281	0.561	1.12	2.24	4.49	8.98	17.96	35.9	71.8	143.7
3	0.315	0.630	1.26	2.52	5.04	10.08	20.16	40.3	80.6	161.3
4	0.354	0.707	1.41	2.83	5.66	11.31	22.63	45.3	90.5	181.0
5	0.397	0.794	1.59	3.17	6.35	12.70	25.40	50.8	101.6	203.2
6	0.445	0.891	1.78	3.56	7.13	14.25	28.51	57.0	114.0	228.1

Table 9: 1951 USAF resolution test target Line Pairs/mm[5]

8 Use of tele-microscopes in the Dr G Scott experiment[4]

8.1 Introduction

The tele-microscopes first use in an experiment at CLF was during the Dr G Scott experiment on Direct Laser Acceleration[4]. During this experiment the tele-microscopes QM-40, QM-41 and QM-43 were used as location references for the foil targets so the users knew when changing the targets that it was in the correct location. This was achieved by marking on screen the position of the target and returning the target to this location.

8.2 Experimental Setup

The tele-microscope QM-40 was used for a top view of the target after being mounted to the gantry on top of the interaction chamber. It was pointed at a mirror that then pointed down at 45° to look at the target. The short-range high-resolution QM-41 was originally setup in this position but it was too far from the target to get a focused image so it was replaced with the long-range low-resolution QM-40. It was positioned approximately 1.8m from the target.

The QM-41 was used for a side view angled at 30° above the horizontal. It was pointed directly at the target as the radius of the chamber is almost the limit of the working distance of the short-range high-resolution tele-microscope. It was positioned approximately 1.2m from the target. However mounting it at this angle introduced some problems with the custom built adjustable stand. The downhill slope meant that in certain orientations different degrees of motion would drift under the pull of gravity. Therefore the only secure position was to have it point directly downhill and not at any angle to the slope.

The QM-43 was used for a bottom view of target. It was positioned on a table out the back of the chamber pointed at a periscope that then pointed to a 2" mirror under the target. This gave a view of the underside of the target taking advantage of the long-range capabilities of this tele-microscope by viewing it through several mirrors ad significantly outside the chamber. It was positioned approximately 3.5m from the target.

8.3 During The Experiment

During the experiment, there was plenty of feedback about the new pieces of referencing equipment from both users and staff alike. Due to the lack of familiarity with these pieces of equipment, the users and staff struggled to learn the basic controls of the tele-microscope. Reading from the user guide written by J. A. Hodson would be beneficial here.

Another example of this is the complaint that the FoV used in this experiment was too small. Before the experiment, the tele-microscopes were set up with zoom 5 which has the tightest FoV. If those running the experiment were more familiar with the tele-microscopes then changing the zoom and therefore FoV would have been much easier. Some other issues that came up during the experiment were that the amount of light needed to image a target was quite considerable. Some small laser diodes were used at multiple angles to image a wire but when imaging a more complex structure light-boxes proved more effective in the short term for referencing but were impractical in the long term.

During the run of the experiment, remote-controlled shutters were used to protect the tele-microscopes and attached CCD's from the laser shots. However, during this experiment, one of the tele-microscopes shields was left open damaging the CCD. It appears that the tele-microscope however was left undamaged. To maximise the amount of spatial information given by the tele-microscopes having 3 tele-microscopes all perpendicular would be optimal. However, in an experimental setting, this is often impractical. During this experiment, there was a top view, bottom view and upper side view. The top and side views were found to be more useful but ideally, the side view would have been lowered to be perpendicular to the top view.

9 Conclusion

By studying the working limits of the resolution and FoV for both the QM-41 and QM-40, as well as the capabilities of the custom-built stand, a wide range of uses of this setup as a referencing tool has been displayed. In J. A. Hodson's last report[1] he describes the versatility of the tele-microscopes and how this versatility allows the QM-41 to be applicable in a diverse range of experimental setups. With the knowledge now of the capabilities of the QM-40 and the stand, the breadth of applications of this equipment has increased massively. To conclude the QM-40 and QM-43 have a much-improved working distance relative to the QM-41 and QM-42 but sacrifice the high resolution available. The QM-41 and QM-42 have a relatively short working distance but has a much higher resolution and the measurements of this were often limited by the pixel size of the camera used in conjunction with the tele-microscope.The custom-built adjustable stand for the tele-microscopes has a lot of potentials but needs some tweaks in design for future experiments. The tele-microscopes performance in the Dr G Scott experiment[4] was enlightening and brought forward some of the limitations and highlights of the new equipment. The extra space provided by moving referencing equipment to the outside of the chamber was extremely valuable, however more familiarity is needed with them. Moving forward the Tele-Microscopes will be a valuable asset to the Central Laser Facility.

References

[1] J. A. Hodson. *Investigating Contrast, Resolution and Field-of-View of the Questar QM-1SZ Tele-Microscope*. Tech. rep. RAL, OX11 0QX, United Kingdom: Central Laser Facility - STFC, 2020.

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