
Reducing the Total Cost of Ownership of Multi-frequency Sieving Systems

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This work is the result of my own investigations carried out within Sandvik Osprey, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s).

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I would like to thank Sandvik Osprey for providing me with the opportunity and support to carry on with my studies and use their facilities to carry out the investigation that went into this report. I would like to thank Szymon Kubal for supporting my ideas and helping me to turn them into a successful project. I would also like to thank my supervisor Peter Charlton for helping me stay on track during such a busy time and providing me with the confidence and motivation I needed. Finally I'd like to thank Angharad Mock for encouraging me to work through hard times outside of my studies and work and provide me and my kids with so much support.

Abstract

Introducing Nylon intermediate meshes into the normal mesh setup for the multi-frequency sieving machines following an aperture (hole size) ratio of 1:10 between the support mesh and the intermediate mesh as well as between the intermediate mesh and working mesh was able to extend the expected life of 32µm meshes by 6.7 times their original tonnage, reducing the overall Total Cost of Ownership (TCO) of the sieving machines to just over 55% of its original cost. Further work on the maintenance schedules, motor frequency, and mesh quality of the sieving machines all proved beneficial towards reducing the TCO further.

Abbreviations

TCO – Total Cost of Ownership

PSD – Particle Size Distribution

AD – Apparent Density

TD – Tap Density

DOE – Design of Experiment

IBC – Intermediate Bulk Container

SWP – Standard Working Procedure

RA – Risk Assessment

MOC – Management of Change

IP – Intellectual Property

MIM – Metal Injection Moulding

AM – Additive Manufacturing

PM – Preventative Maintenance

TPM – Total Productive Maintenance

RM – Reactive Maintenance

KE – Kinetic Energy

SD – Standard Deviation

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1. Introduction

1.1 Report Focus

The aim of this report is to investigate how the Total Cost of Ownership (TCO) of multi-frequency sieving systems can be reduced. The different elements that make up the TCO were reviewed to find which areas needed to be focussed on to reduce costs. Based on empirical understanding, the consumables, primarily the meshes, are the largest cost consideration with sieving systems and also provide the most opportunity for improvement. For this reason mesh failure was investigated and methods of reducing this failure was researched and implemented.

1.2 Organisation of Dissertation

In the remainder of the introduction the process background of the industry, sieving systems, and harmonic sieving machines are discussed. Following this an explanation of TCO is given including a definition. Aims and objectives are then defined just before giving a breakdown of the actual TCO total into focus categories.

Chapter 2 looks into the meshes used in sieving machines. The section starts with mesh usage, explaining how and why meshes are used as well as their common life expectancy which identifies a cause for investigation. It continues with common causes of mesh failure, introducing blinding and mesh fracture including modes of prevention and recovery, leading into the practical investigation of the meshes used. Further to this, research is done into the available improvements that may help to prevent the failures seen in the investigation, highlighting the use of intermediate meshes. Finally based on the idea of using intermediate meshes, a timing plan for a trial is given.

Chapter 3 runs through the intermediate mesh trial, looking at using either stainless steel or synthetic (Nylon) meshes as an intermediate mesh, and as a working mesh, looking to improve the total throughput over the meshes. Methodology of the setup and the test equipment is discussed, along with the hypothesis for the trial. A Design of Experiment (DOE) is done to show how the trial is carried out. The data collection and results of the trial is then discussed including the problems encountered and variations to the expected hypothesis. Finally, the practical implications of the change are highlighted, explaining how this will be implemented and how it will affect the business.

Chapter 4 reviews the timing plan as the trials in Chapter 3 were able to be done faster than expected. This allows for some extra investigation work to be done into other potential improvements that could reduce the TCO. This includes an improvement to the sieving machine maintenance schedules, a trial on the motor frequency setup of the sieving machines, and an investigation into the quality of the meshes, and the implications that could have in terms of sieving efficiency and cost reduction. This additional work provides a well-rounded approach to cost reduction.

Chapter 5 presents the final cost implications of the changes proposed and completed, as well as talking about the conclusions from the work, and possible recommended further work that could be done.

1.3 Process Background

In the metal powders industry, in the process of making fine metal powders for applications such as Metal Injection Moulding (MIM), Spray Forming, Hard-surface Coatings, Additive Manufacturing (AM), and Screen Printing, the metal powders need to be sized to accurate size bands suitable for the application. As produced, metal powders have a varied Particle Size Distribution (PSD) ranging from around 0 - 500 μm , but for practical use this is not suitable as particles above or below certain sizes may not be usable in the application, or a PSD that promotes a secondary

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characteristic such as flow or packing density may be required. In order to achieve the required PSD, sizing equipment is used, which in most cases is a Sieving Machine.

A Sieving Machine is a machine that vibrates a “Screen” which is a mesh made of woven metal wires held or tensioned onto a metal ring, using motors. By passing material over the mesh while it’s in motion, they separate the material into two parts, a coarse part and a fine part as shown in Figure 1. In normal operation the material is fed onto the mesh at a consistent feed rate, usually in the centre to allow the material time to pass through the mesh. The material that is smaller than the mesh size passes through and falls into a container underneath. Material that is larger than the mesh size is unable to pass through and works its way towards the edge of the mesh where it is diverted into a separate container. Hence, the size of particles allowed to pass through the mesh based on its nominal hole size or aperture determines the size of each of the new material fractions.



Figure 1 - Sieving Illustration (Russell Finex, 2023)

The type of sieving machine that was looked at in this report is known as a Multi-frequency Sieving Machine. This type of sieving machine uses two motors, one either side of the machine at an angle to the mesh which run at the same frequency, creating a rotational vibration. A second frequency is then applied to the mesh using a beater/agitator ring under the mesh which is a stationary ring that the vibrating mesh contacts, breaking the normal frequency and adding another as seen in Figure 2. This type of sieving machine provides a very high sieving energy allowing for fast efficient sieving. Multi-frequency sieving machines are a new technology when compared with more traditional sieving systems, and as such there is little information available regarding their ideal operational setup.

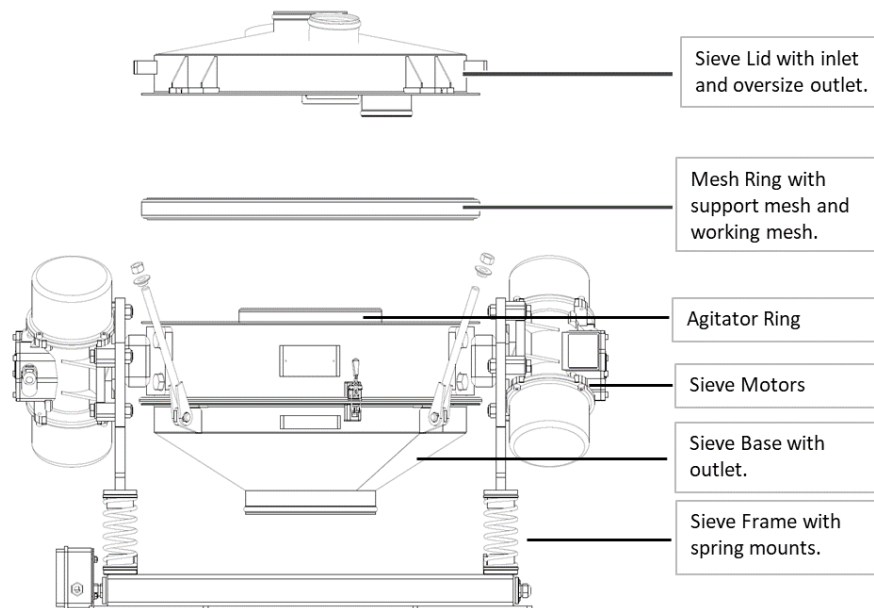


Figure 2 - Breakdown of Virto X-Screen Multi-frequency Sieve (Virto 2017)

1.4 Total Cost of Ownership

“Total cost of ownership (TCO) is an estimation of the expenses associated with purchasing, deploying, using and retiring a product or piece of equipment.” (Bigelow, 2024)

Total Cost of Ownership (TCO) is the sum of the cost of the equipment and the cost of running that equipment through its life expectancy (Bigelow, 2024). Due to the long expected life of sieving machines the TCO is largely based on the cost of running rather than the initial cost of the equipment. As such it is possible to reduce the TCO by reducing the running costs of the equipment which makes running existing equipment as well as investing in new equipment more viable.

With this in mind, in order to reduce TCO of the Sieving Machines, maintenance work including replacement parts as well as repairs need to be considered, however production consumables make up the bulk of the costs. The production consumables for the sieving machines are primarily meshes, however they also include flexible connections, clamping parts, and other mechanical components.

1.5 Analysis of Costs

In order to understand which areas needed the most focus, analysis of the costs needed to be done. A breakdown of the cost areas included in TCO and a TCO calculation proved how the TCO could be reduced, and where the focus needed to be.

TCO can be expressed as the initial purchase price plus the operating costs over the expected lifespan of the equipment (Bigelow, 2024). Based on practical knowledge, sieving machines if maintained correctly, have a lifespan of roughly 40 years. Based on this assumption a TCO was estimated. The following breakdown in Figure 3 includes a comparison of the purchase cost, and one year of running broken into mesh costs, labour costs, and maintenance component costs. The production consumables apart from the meshes were included in maintenance spares as they are negligible.

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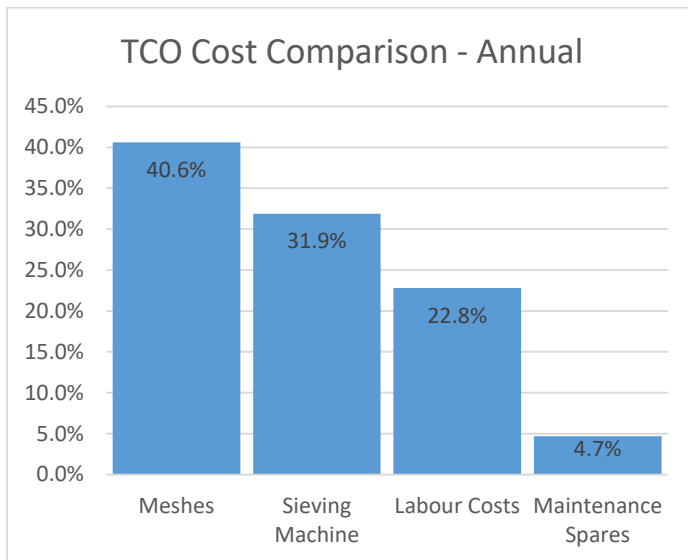


Figure 3 - TCO Cost Annual

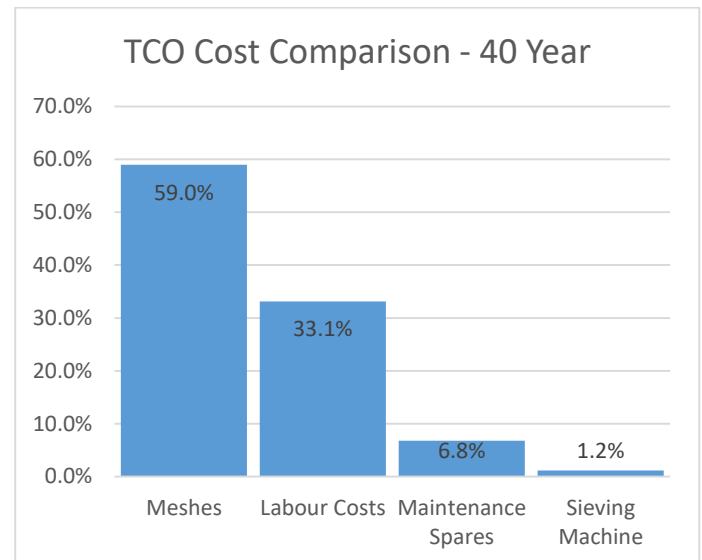


Figure 4 - TCO Cost 40 Years

Factoring in the 40 year expected life cycle the second graph in Figure 4 was generated. The initial cost of the machine was then only 1.2% of the TCO, so the TCO is not reliant on the machine cost. Maintenance spares are also insignificant at 6.8% of the total TCO. Labour costs cannot be easily reduced due to fixed production rates so this leaves the meshes, the primary consumable of the sieving machines, which is the majority of the TCO proving that meshes are the required focus area.

1.6 Aims and objectives of the project

The project was based on the following aims and objectives.

1.6.1 Aim

To reduce the total cost of ownership of multi-frequency sieving systems by reducing high running costs.

1.6.2 Objectives

- Investigating the failure modes that are leading to frequent mesh failure.
- Researching improvements to the mesh or machine setup that can reduce failure rate.
- Trailing and comparing improvements, noting which are standard, and which haven't had enough testing.
- Proposing improvements of sieving efficiency through altering the sieving parameters.
- Reduce mesh change time by improving the standard setup.
- Investigate potential improvements to the mesh quality.
- Propose improvements to the maintenance of the sieving systems.
- Ensure key powder characteristics are not negatively affected by the changes.

2. Mesh Faults & Investigation

2.1 Average Mesh Usage

Meshes are a consumable item and only have a certain life expectancy. In the majority of industries where light goods such as pharmaceuticals or food products are being sieved, the life expectancy can be as high as a number of months, however in the metal powders industry where dense powders with a similar hardness to the meshes are used, this is dramatically shorter, only lasting roughly between 500kg – 15,000kg or a number of days depending on the mesh type, sieving machine setup, and powder being processed.

Meshes can fail for different reasons, some failure modes can be recovered while others cannot. Investigating these failure modes helps to understand what causes the meshes to fail so quickly allowing the failure to be prevented.

2.2 Mesh Failure Modes

The majority of mesh failure can be split into two groups, Blinding and Fracture.

2.2.1 Blinding

Blinding is where material becomes trapped in the apertures of the mesh, reducing the mesh's open area and therefore it's efficiency. If a large amount of blinding happens the mesh can become unusable as particles smaller than the mesh apertures will begin being discharge off the top of the mesh. One mode of blinding is called Pegging as seen in Figure 5, which is where single particles slightly larger than the mesh aperture get lodged in the apertures blocking the majority of the aperture. The other mode is called Agglomeration as seen in Figure 6, which is where adhesive or cohesive powders gather around the apertures, blocking them with many smaller particles. According to a study, agglomeration blinding can also be caused electrostatic charge in particles, it states, "Ultra-fine powders often coat the mesh cloth, causing a blinding effect through an electrostatic charge". (Bilal, 2015)

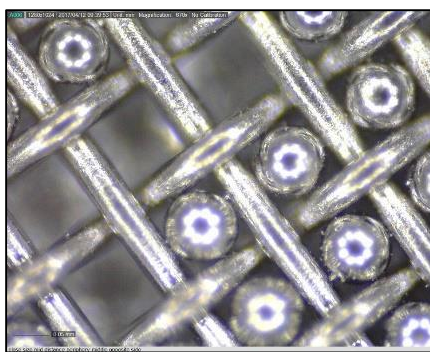


Figure 5 - Mesh Pegging (Elcan 2023)



Figure 6 - Mesh Agglomeration (Virto, 2024)

Blinding failure can be recovered by agitating the mesh allowing the trapped particles to release from minor movements in the mesh wires, or by pushing the particle back out the apertures through brushing or blowing through with high pressure air. During production it isn't possible to brush or blow the mesh, but it is possible to apply a second frequency of agitation to clear the pegging as it happens. The multi-frequency sieves use the agitator/beater ring for this purpose while traditional sieving machines often employ ultrasonic systems to achieve a similar result. Between batches the meshes can be brushed and blown through to ensure they are recovered as best as possible for re-use.

2.2.2 Fracture

Fracture is where the wires that make up the mesh break, allowing larger particles to pass through. Meshes are very delicate and fracture can happen from minor impacts, work hardening, or abrasion from product.

Mesh fracture from incidents can be avoided by taking care of meshes and handling them delicately, but fracture from work hardening or abrasion in normal use is much harder to prevent, however fracture from wear can be caused by poor design or operation of the system and as such can be reduced.

Some common examples of process issues that can cause mesh fracture are:

- Overuse of de-blinding mechanisms such as ultrasonic systems, causing premature work hardening as seen in Figure 7.
- Overfeeding of material onto the mesh causing stretching and weight fracture of the mesh.
- Feeding of very large parts onto the mesh, causing impact fractures, as seen in Figure 8.



Figure 7 - Mesh Fracture from Impact



Figure 8 – Mesh Fracture from Work Hardening

Failure during production will mean the current batch needs to be completely re-processed as large particles will pass through the fracture. Preventing this wear would extend the life of the meshes and therefore reduce the cost of consumables, and the cost of reprocessing.

It is important to understand how a mesh is failing so prevention methods can be considered. As such an investigation was done onsite at Sandvik Osprey into the failure mode that was causing the meshes to break prematurely as described in the following chapter section.

2.3 Mesh Failure Investigation

The meshes used on the multi-frequency sieves were failing frequently at very low production volumes. Traditional rotary sieving machines have an average mesh life of 5-10 tonne on fine meshes, and 10-15 tonne on courser meshes, while the multi-frequency sieving machines were only seeing 1-2 tonne on fine meshes and around 5 tonne on courser meshes before they were failing.

The mesh material used on both systems is the same, from the same manufacturer, however the mesh setup and machine operating principles are very different. Traditional sieving machines use pre-tensioned meshes with ultrasonic de-blinding systems, while the multi-frequency sieving machines use slack manually assembled meshes and an agitator/beater ring for de-blinding. The operating principle of traditional sieves creates a low energy rotatory motion using a bottom mounted motor on a flexible coupling with an off-centre weighted shaft to create a rotary

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vibration pattern on the mesh while ultrasonic sieving machines use two side mounted motors to create a similar, but much higher energy vibration pattern.

Understanding whether the failure of the meshes is simply down to the difference in the systems, or if there is a common failure mode to the ultrasonic sieving machine meshes will allow for a focussed approach as to how to prevent the failure. As such a visual investigation of failure on the two systems was done.

Firstly the traditional rotary sieving machine meshes were inspected after failure. Here there were a number of different failure modes seen including impact fracture and work hardened fracture, however the majority of failures were due to stretching of the mesh over time leading to eventual fracture. This was from the weight of the material during processing gradually stretching the mesh through prolonged use. These failure modes were expected and are typical of a mesh that's been well used.

Following on from the traditional rotary sieving machines, the multi-frequency sieving machine meshes were inspected in a similar manner, however every failure was the same, showing a unique style of failure as shown in Figure 9.



Figure 9 – Examples of Unique Wear on Multi-frequency Sieves

Unlike the rotary sieving machines, the multi-frequency systems use a support mesh which is a sturdy 3mm aperture mesh with thick wires that is used to support the slack working mesh on top, and acts as part of the de-blinding mechanism for the working mesh. The support mesh hits the beater ring underneath as the sieving machine vibrates creating a shock which knocks any blinding out of the mesh, but it also creates a lot of friction which was wearing holes in the mesh. Below in Figure 10 is a multi-frequency sieving machine without it's working mesh or is lid, showing the support mesh, and through the mesh the beater ring can be seen.



Figure 10 - Multi-frequency Sieving Machine Without Working Mesh

Due to the large amount of force generated during the sieving process on these sieving machines, a huge amount of friction is generated. In most applications a more rigid working mesh is used so the wear is not much of a problem, however when working with the fine meshes used in the metal powder manufacturing industry, they wear very quickly due to this friction.

2.4 Available Improvements

Literature relating to wear prevention of wire mesh usually focusses on structural wire mesh used for fencing and reinforced concrete where coatings are used which aren't applicable to sieving systems. There is very little information available for fine screening meshes used in sieving machines as the sieving industry is highly competitive and most information is restricted Intellectual Property (IP), this is even further reduced when looking at sieving systems used for metal powders which are unique due to the high wear rate of meshes seen in this area.

Due to the very limited literature available, talking directly to specialists in the industry was more likely to yield useful information, and as such Virto who are the primary manufacturer of multi-frequency sieves were contacted to ask about their experience with the wear mode seen in the investigation. Through conversation with Virto it became clear that although they were familiar with the wear pattern, they had done limited testing themselves in that area as their focus is largely on courser meshes, and their customers also don't often share their findings with similar investigations, however they were more than happy to discuss the topic further and to endorse the investigation work done at Sandvik Osprey, and as such a meeting was organised with their technical team to discuss ideas.

2.4.1 Intermediate Meshes

The technical team at Virto suggested an idea that they were aware of, which was to use a midsize mesh in between the sieving machines support mesh and it's working mesh, this is referred to as an intermediate mesh. Their knowledge of what mesh to use in this application was limited due to a lack of test data, however they were able to suggest the following rule which was published by one of their old engineers who had done some testing back in 2017:

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"The ratio between the opening dimensions of the mesh must not exceed 1:10. If the ratio of openness between support and work meshes is greater than 1:10, it will be necessary to install an intermediate mesh." (Virto, 2017)

The standard support mesh aperture is 3mm or 3000µm, so following this rule, any mesh smaller in aperture than 300µm should use an intermediate mesh. This means all meshes used in the metal powders industry should use an intermediate mesh.

When talking to Virto about what mesh size and material to use, they suggested sticking to a similar size rule to the one above, and try both a synthetic mesh and a stainless steel mesh. The most common synthetic mesh used is Nylon, which is readily available. They also suggested trying a synthetic working mesh. Virto were happy to supply the relevant meshes and measure them for exact size to support the trial work.

In order to maintain the 1:10 ratio with both the support mesh and the intermediate mesh, a 300µm intermediate mesh was needed, so a 300µ Nylon mesh and a 300µm stainless steel mesh were supplied. For interest to see if the 1:10 rule applied to the intermediate mesh, a 700µm Nylon mesh was also supplied. For testing the Nylon working mesh Virto also supplied a 32µm working mesh.

Due to the lack of alternative information, and the available support of the supplier, the use of intermediate meshes is the best known option for reducing the wear seen on the multi-frequency sieving machine meshes due to its clear method of wear reduction, low contamination risk, low cost, and easy installation. As such, this was the option selected for implementation.

Some other ideas for potential improvements were also discussed, this included checking the maintenance of the beater ring assembly, altering the motor frequency of the sieving machine, and investigating the quality of the working mesh being used. These options were less likely to make a big impact on the mesh wear, but would help to make minor improvements.

3. Mesh Material Trials

In order to implement the intermediate meshes in the sieving systems a trial was planned. The trial's intention was to test the actual wear reduction provided by intermediate meshes. In the following chapter the trial plan is discussed.

3.1 Methodology and Equipment Setup

3.1.1 Machine Setup

The trials took place on one of our Virto X-Screen 650 multi-frequency sieving systems. These are full production scale sieving machines fitted into a framework that's designed to feed material from a source Intermediate Bulk Container (IBC) to the sieving machine. Product and revert IBC's are fitted underneath the sieving machine to collect the material once it has been sieved. This can be seen in Figure 12 below.

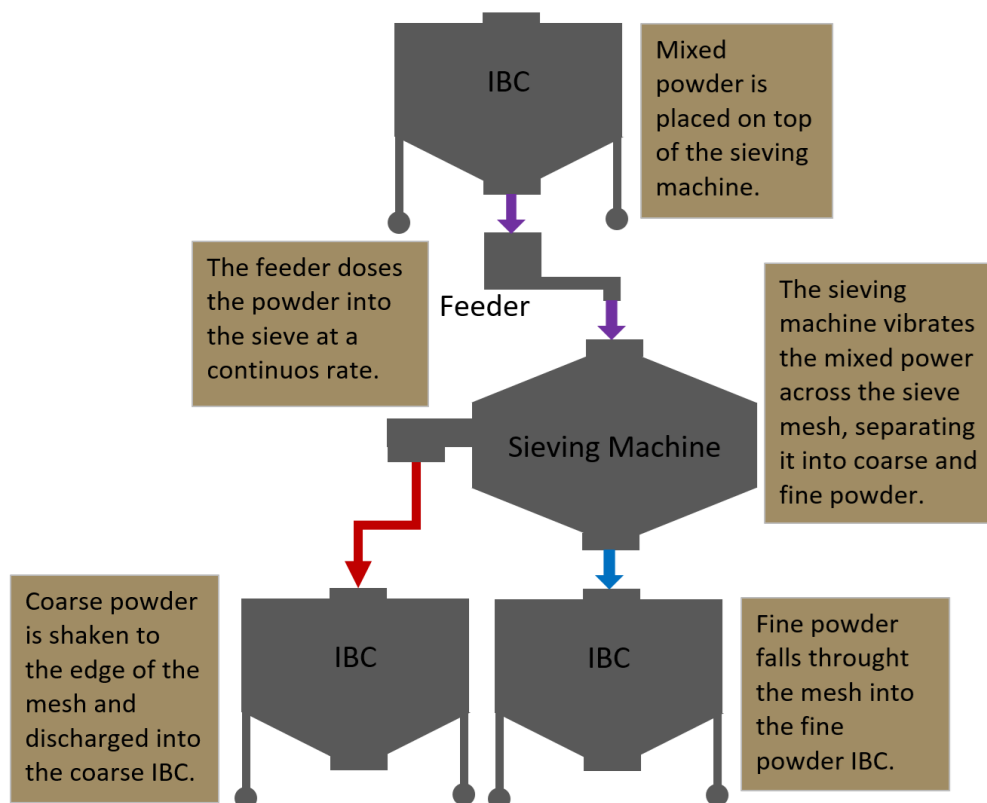


Figure 12 - Sieving System Flow Diagram

These systems are fully enclosed to ensure fine powder doesn't become airborne and present a risk to the environment and operators. This means that during production only limited inspection of the mesh can be done through a small viewing port.

In order to make sure the trials were consistent, the same sieving system was used for all trials.

3.1.2 Trial Setup

Meshes are commonly available in Stainless Steel as well as Nylon. These materials have vastly different material properties so they were both likely to give different mesh life results. There are also two mesh sizes that could work well for intermediate mesh, so there are a number of trials that needed to be done.

A batch of powder is 1000kg, and takes roughly 22 hours to sieve. Each of the trials were ran until failure with a target life cycle of 3000kg, this means each trial would run for roughly 66 hours of processing time. Between each batch the sieving machine needed to be disassembled to inspect the condition of the mesh to see if any damage had been done to it. This process could take a couple hours per batch also, making the total time around 3 days. Based on this a week per trial was expected to account for testing and analysis time.

In order to allow the trial to run during all production hours, training of the operators in the installation of the intermediate meshes was needed. This was done in the two weeks prior to the trials starting once documentation was written. The documentation done included the Standard Working Practice (SWP), Risk Assessment (RA), and Management of Change (MOC), these were done before training to ensure the operation was safe and feasible. Even with this planning there was still a risk that if something unplanned happened during the trials and outside of normal office hours the sieving system would be down until morning, so this was also factored into the timing expectations.

3.1.2 Mesh Setup

The meshes used in the multi-frequency sieving machines are normally made up of a stainless steel ring with a bonded 3mm stainless steel support mesh and a stainless steel working mesh of the size required for processing the powder which is held on with a gasket, as shown in Figure 13.

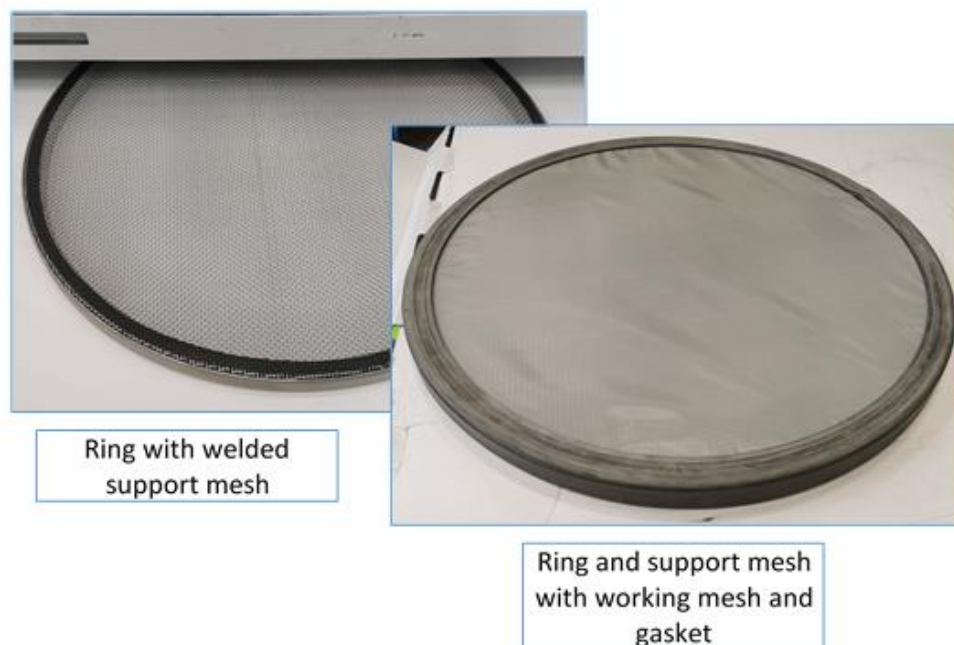


Figure 13 - Example of Normal Multi-frequency Mesh Setup

The intermediate mesh is added to the mesh assembly in-between the support mesh and the working mesh to reduce the friction on the working mesh as seen in Figure 14. The intermediate mesh is made of thicker wire with an aperture size between that of the other two meshes so it can resist wear better than the fine working mesh.

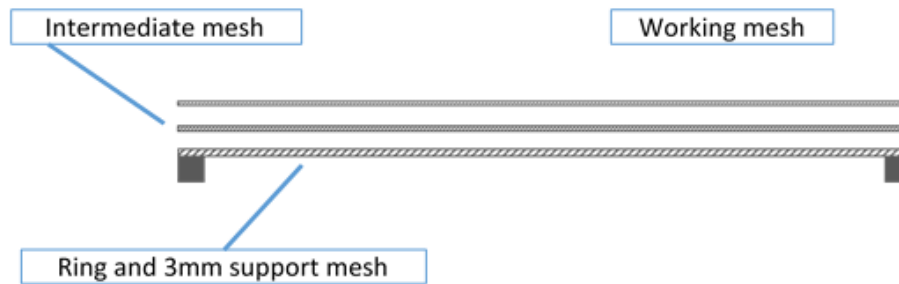


Figure 14 - Trial Mesh Setup with Intermediate Mesh

Nylon mesh has a higher abrasion resistance than the Stainless Steel mesh, which is reason to believe the wear on the Nylon mesh will be less. As such, there is also a possibility that using Nylon working mesh may improve mesh life, but it does come with an added risk of contamination if the mesh is to wear. Due to these unknowns, trials with different material meshes were done. Lifecycle of each mesh setup was tested.

3.2 Expectations and Variables

Based on the above information, the trials were designed using the following hypothesis:

- The use of Nylon intermediate mesh will improve the lifecycle of the mesh setup.
- Nylon working mesh may improve the setup, but also may change the test results, having an impact on quality.

There were a number of unavoidable variables that may affect the outcome of the trials. Some of which are as follows:

- Variation in the operators running the machine and setting up the meshes will have an impact.
- Alternative failure modes of the mesh may cause data variation.
- Wear is not predictable, meshes can wear at very different durations with the same setup.

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3.3 Design of Experiment

The following experimental design was done to test a good variety of possible mesh setups while minimising the effects of the known variables. The available mesh setups had different combinations of working and intermediate meshes, allowing results from durability of both meshes to be tested. The trial plan can be seen in Table 1 below.

Machine:	Virto X Screen 650 Sieving Machine							
Trial Duration:	8 weeks							
Aim 1:	To improve the mesh life of the multi-frequency sieve meshes, reducing downtime and cost of replacement.							
Aim 2:	To maintain or improve the apparent density and sieving efficiency of the systems.							
Objective:	A series of trials will be carried out on different mesh setups, testing the total achieved tonnage.							
Mesh	Trial 1	Trial 2	Trial 3	Trial 4 (current)	Trial 5	Trial 6	Trial 7	Trial 8
Working	Nylon 32 µm	Nylon 32 µm	Stainless 32 µm	Stainless 32 µm	Nylon 32 µm	Stainless 32 µm	Nylon 32 µm	Stainless 32 µm
Intermediate	Nylon 300 µm	Stainless 300 µm	Nylon 300 µm	-	-	Nylon 700 µm	Nylon 700 µm	Stainless 700 µm
Support	Stainless 3 mm	Stainless 3 mm	Stainless 3 mm	Stainless 3 mm	Stainless 3 mm	Stainless 3 mm	Stainless 3 mm	Stainless 3 mm
Each setup will use a new 32-micron aperture mesh. Once trials have concluded, the best setup will be also tested on 38 micron to test the relative improvement on more durable meshes. Each setup will be tested to failure, aiming for 3000kg. Current setup (4) lasts for roughly 1000kg - 2000kg from information provided by operators. Testing requirements will be as follows: Tonnage Capability (kg total) Apparent Density of Product (g/cm3) % of Product in the Revert } Overall Sieving Efficiency % of Revert in the Product								

Table 1 - Design of Experiment for Mesh Trials

The trials were prioritised by likelihood of producing good results to mitigate the risk if the project is cut short, following the hypothesis set out in chapter 3.2.

3.4 Required Powder Testing

In order to ensure the trials were successful they needed to prove a longer life cycle without negatively affecting any other process parameters of the powder. A negative effect on the powders production tests could lead to the powder being out of spec for the customer, or even if the powder is in spec the change could be significant in the end use of the powder for the customer, leading to a failure or reduced productivity in their process.

The following tests are done on the powder being used for the trials:

- Particle Size Distribution (PSD)
- Apparent Density (AD)
- Tap Density (TD)

Another test that's carried out on the powder is the sieving efficiency. This does not directly affect the powder quality for the customer, however if the sieving efficiency is reduced then the product yield will drop, leading to a cost increase as more powder will need to be produced to meet the order requirement.

3.4.1 Particle Size Distribution

Particle Size Distribution (PSD) was tested on a system called the Malvern 3000 laser diffraction analyser. This system passes a small sample of powder passed a series of lasers, and based on the diffraction of the lasers it can determine the size of each particle in the powder. This outputs a data curve showing the distribution of particles in a log distribution as shown in Figure 12. A log scale is used as the as-atomised powder follows a log normal distribution curve.

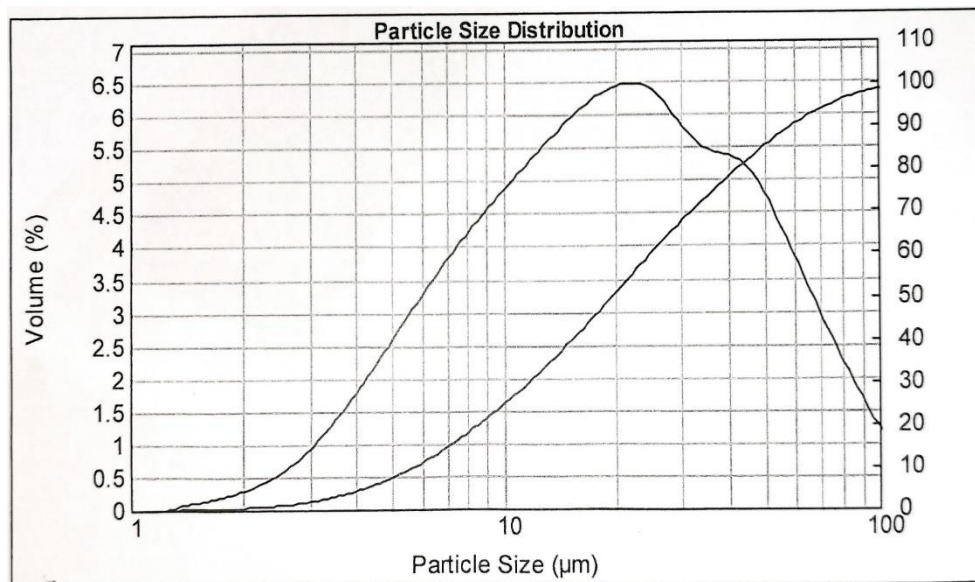


Figure 15 - Example of a Log Distribution Generated by the Malvern 3000.

There are three methods of reporting PSD of the powders as follows:

D Numbers

A number of required distribution bands referred to a "D Numbers" can be used. These are percentage bands, so the D10 is the point where 10% of the powder in terms of volume is below e.g. a D10 of 6μm would mean 10% of the powder is below 6μm. The normal D Numbers used are D10, D50, and D90.

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Percentage Less Than

Particle size requirements may also be reported as a percentage less than a set micron value, this is used where a quantity below the size is required, but the actual micron value isn't important. Normally used for fine powders. E.g. 90-92% -22 means 90-92 % of the total powder volume must be below 22µm.

Percentage Above/Below

When a certain volume above or below a set micron size is required, it is reported as the measured value against the target e.g. <5% +38µm or >2% +5µm

These tolerances are built into a specification either specified by the customer or suggested to them, known as customer specifications. A different specification may be used for standard product or where a change is needed internally to make the powder effectively, this is called an internal specification. An internal specification was used to test the results against to prove the powder has not been negatively affected.

3.4.2 Sieving Efficiency & Yield

Sieving efficiency is a measure of how well the sieving machine has separated the material. This is described using two measurements, percentage of product powder contained in the revert powder, and percentage of revert powder contained in the product powder. Both of these are measured in the same way using a process called hand sieving.

Hand sieving is using a calibrated test sieve, where the apertures are measured to a high standard, and sieving a sample of a known weight, following ASTM-B214 (ASTM, 2015). Both the resulting fractions are weighed so a percentage can be calculated. For example, if the product is the material under the mesh size, a product sample is sieved and the percentage of powder remaining on the mesh is the percentage of revert in the product.

The specification will determine how much revert is allowed in the product powder, as this will affect the end use of the powder, however the amount of product in the revert is a loss to the process which needs to be minimised for cost reasons. As a certain loss of efficiency is expected, the loss may be allowed to increase to ensure the product is within specification.

The loss from the percentage product in revert will ultimately affect the product yield. The yield is the percentage of saleable product from the original feed stock used. An expected yield can be estimated from the PSD of the as-atomising powder and the product size range, but this will be reduced by any losses in the process, so these are factored in when estimating. As such a good sieving efficiency is important.

3.4.3 Density Testing

There are two key density figures used in powder manufacturing, Apparent Density (AD), and Tap Density (TD).

AD is a measure of how dense the powder is when dropped from a set height and will account for an amount of aeration and poor packing. This was tested on our internal AD testing setup following the ASTM_B703 / MPIF 48 standard for Arnold Apparent Density, which is used for non-flowing powders (ASTM, 2010) as shown in Figure 13.

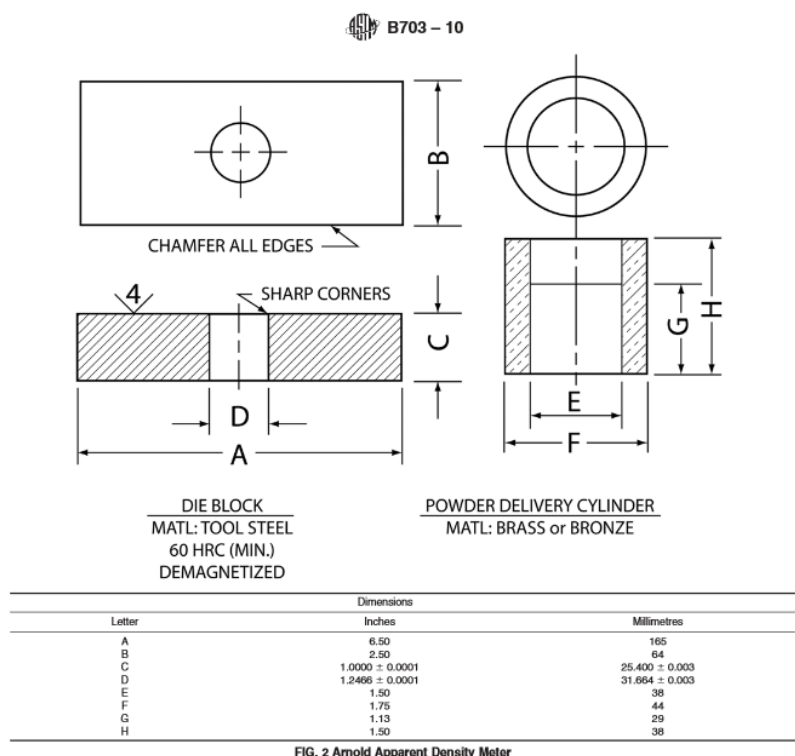


Figure 16 - Arnold Apparent Density Equipment. (ASTM, 2010)

The standard method for free flowing powders is the Hall Apparent Density method, following ASTM B212 (ASTM, 2021). The equipment is shown in Figure 14 below.

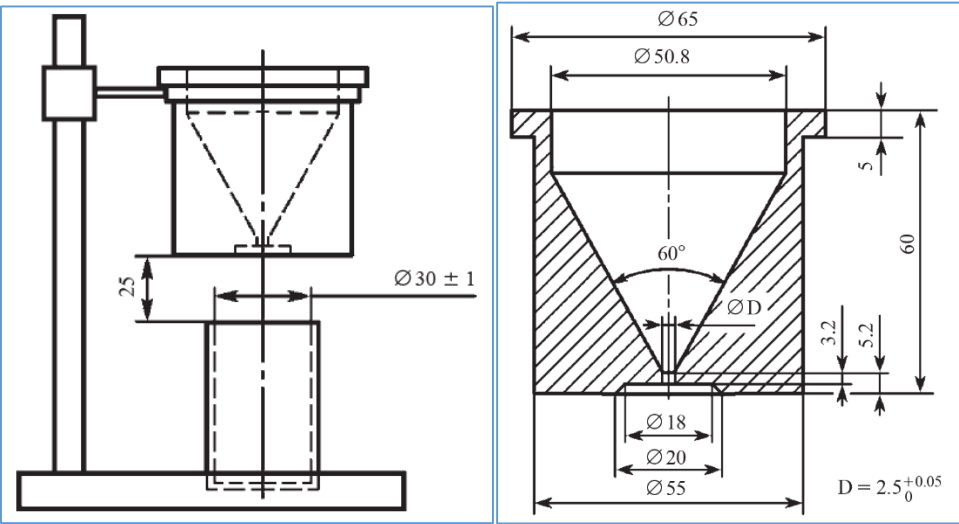


Figure 17 - Hall Apparent Density Equipment Setup. (Neikov et al., 2019)

TD is a measure of how dense the powder is after a set number of taps, which will compact the powder. This is done according to ASTM-B527 (ASTM, 2022). The test is carried out in a flanged test tube, which is clamped to a holder which is lifted and dropped using a motorised cam underneath as shown in Figure15 below.

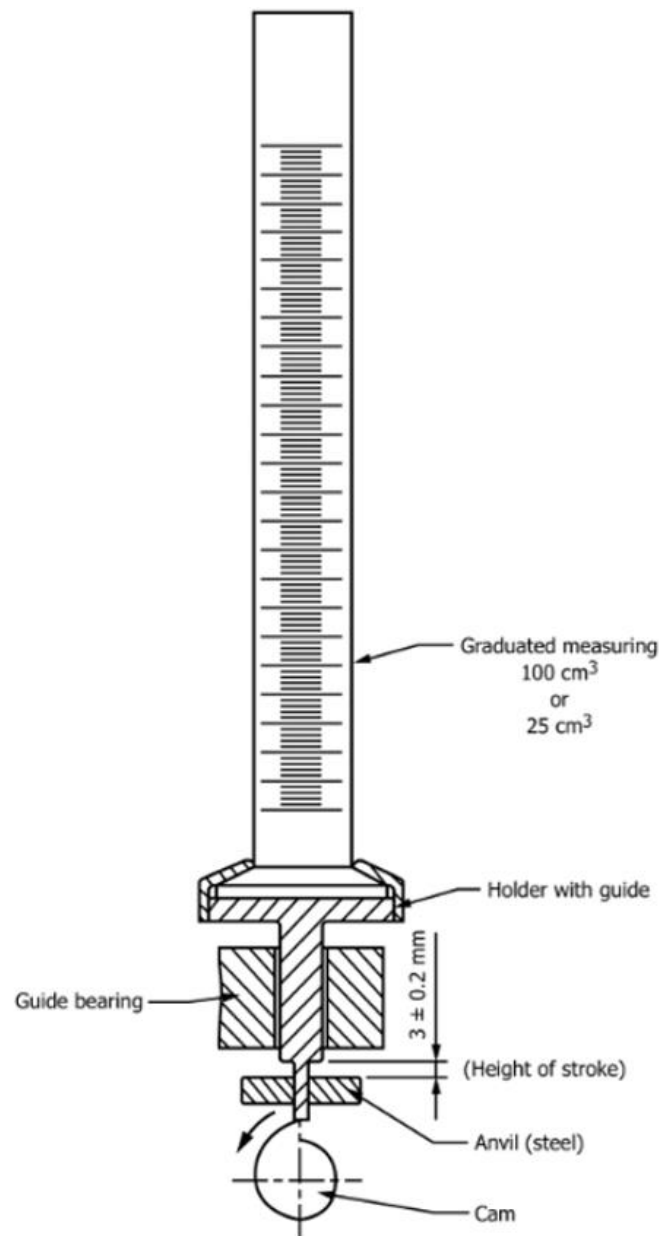


FIG. 1 Example of Tapping Apparatus

Figure 18 - Tap Density Equipment Diagram (ASTM, 2022)

All test results were compared with an internal specification to prove they have not been negatively affected after each trial setup. The results of all tests were recorded along with the tonnage results, which can be seen in chapter 3.6.

3.5 Data Collection

Data from the life expectancy (tonnage) testing was collected along with any production comments by referencing the total kg processed on our internal management system. If the mesh failed mid batch, the time of failure was recorded as a comment, and a new setup was started on a new batch.

Standard tests such as PSD, AD, TD, and sieving efficiency will be done at the end of each batch by the operators as per standard production. If the mesh failed midway through the first batch no standard testing was done for that batch. PSD, AD, and TD are recorded in the company's production management system, however sieving efficiency is not recorded as it's not important to the customer, and the result is only needed during the production run, as such a trial

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sheet was put in place to collect the sieving efficiency test data independently. This was included in the training for the trials.

3.6 Results

Once the trials were complete, the results were compiled from the internal production management system, and the trial sheets. These results can be seen in

Table 2 below.

Trial	1	1.2	2	3	4	5
Working	Steel	Steel	Nylon	Steel	Nylon	Nylon
Intermediate	Nylon	Nylon	N/A	N/A	Nylon	Steel
Tonnage	3706	3789	1019	562	4428	1548
Avg. Feed Rate	32.06	34.29	29.98	40	34.19	21.62
Avg. D10	4.36	4.15	N/A	N/A	4.26	4.46
Avg. D50	13.87	12.84	N/A	N/A	13.66	15.03
Avg. D90	28.52	28.89	N/A	N/A	29.80	34.17
App. Density	4.01	4.02	N/A	N/A	3.90	3.86
Tap Density	4.60	5.03	N/A	N/A	4.85	4.88
% Product in Revert	4.44	2.03	N/A	N/A	9.90	8.00
% Revert in Product	0.50	0.57	N/A	N/A	0.31	0.00

Table 2 - Mesh Trial Results

The Trial numbers in

Table 2 relate to the trial setups in the DOE (Table 1). Trial 2 and Trial 3 are missing test results as they failed before a single full batch finished, and the test data is taken after the batch is complete. As Trial 3 is the normal setup, a comparative dataset was taken from the batch before the trials, see Table 3.

Avg. D10	Avg. D50	Avg. D90	App. Density	Tap Density	%Product in Revert	%Revert in Product
4.2	13.4	29.6	4.11	5.13	6.31	1.14

Table 3 - Comparative Normal Setup Data

The density values vary between the trials, but the difference is small and is not considered to be a significant change. The PSD data is close between the trials, and once again is not considered to be a significant change. The tonnage that each setup managed to process before breaking is starkly different. Each trial shows that there is a positive improvement when using intermediate meshes, and when using Nylon meshes.

The sieving efficiencies are interesting as all the trials showed a lower percentage of revert in the product than the normal setup which is a positive from a quality standpoint as excessive revert in the product can cause problems for the customer. Sieving efficiency can be expressed as the sum of the % product in revert and % revert in product, where the smaller the value is the better efficiency is, as shown in Table 4. From this data it is clear to see that Trial 1 and 1.2 had a better sieving efficiency and Trial 4 had the worst sieving efficiency.

Trial	1	1.2	3	4	5
% Revert in Product	4.44	2.03	6.31	9.9	8
% Product in Revert	0.5	0.57	1.14	0.31	0

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Sieving Efficiency	4.94	2.6	7.45	10.21	8
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Table 4 - Sieving Efficiency

3.7 Problems Encountered

Despite good trial results, there were some problems encountered with the trials. Firstly the stainless steel intermediate mesh was difficult to setup since it was thick and hard to shape around the frame, this led to some inconsistencies in the mesh surface which could lead to premature failure. The stainless steel intermediate mesh will not be used for this reason.

Trial numbers 6-8 were not tested as the 700 µm Nylon intermediate mesh was deemed a low priority and material wasn't available to do more trials at the time. Making material available would mean producing material that didn't yet have an order, increasing inventory and risking it not being sold, and further orders of the same material were not due to be made during the period of the report. For this same reason, testing the 38µm meshes on the same material was not possible. This however did mean that time expected to be spent on the trials was freed up for additional work.

Trial 1 was ran an additional time, as Trial 1.2, as the mesh was removed prematurely during Trial 1 due to miscommunication across the shifts stemming from operators not trained for the trials being requested to do the clean down between batches. A further communication was then sent to the whole workforce to inform them of the trials so a repeat would not happen. In hindsight, this communication should have been sent out before the trials started. Despite this the tonnage seen in Trial 1 is very similar to Trial 1.2.

Trial number 4 caused minor contamination of the last batch it processed, with small pieces of Nylon mesh detectable in the samples when viewed under a microscope. This contamination was minor and only produced after the mesh failed, and in some customer applications this type of contamination would be unlikely to cause a problem in production, however there is a risk that it could cause a problem downstream and as such it is an unacceptable failure.

3.8 Expectation Vs Actual

Based on the initial two hypothesis there were some unexpected outcomes.

Hypothesis 1 – Nylon intermediate mesh will improve mesh life.

The use of Nylon intermediate mesh did indeed improve the mesh life, and it exceeded the 3000kg target, with both Trial 1 and 1.2 achieving over 3700kg compared with the 562kg of the standard setup in Trial 3, increasing the life expectancy by 6.7 times. It was surprising to see the consistency of tonnage between the two trials, especially as Trial 1 failed midway through a run, but this does indicate a good reliability of the setup.

The Nylon intermediate mesh also improved the overall sieving efficiency meaning less waste and less chance of quality issues.

Hypothesis 2 - Nylon working mesh may improve the setup, but also may change the test results, having an impact on quality.

The Nylon working mesh also had a much high tonnage than expected, getting to 4428kg. This is an impressive tonnage as it allows 4 batches to be processed before a mesh change. The Nylon working mesh was also easier to install than the normal steel mesh due to reduced rigidity.

The test results for the Nylon working mesh were unfortunately poor with a worse sieving efficiency than the standard setup when used with a Nylon intermediate mesh, and a similar sieving efficiency to the standard setup when using a stainless steel intermediate mesh.

3.9 Practical Implications

3.9.1 Nylon Inclusions

Using Nylon meshes presents a risk of contamination that is dissimilar in chemistry to the product being produced, so there's a risk to the end use of the powder. In order to check if this contamination is present in the trials samples were taken of the product after each mesh broke. Visual analysis on an optical microscope was done on each of the samples, and the samples were also sent off for chemical analysis looking for a sudden increase in Carbon when compared with the chemical specification.

The samples using the Nylon intermediate mesh passed both of these checks, however the samples using the Nylon working mesh showed visual evidence of Nylon inclusions even though there was nothing picked up on the chemical analysis, potentially due to sample size used in the test. This was because when the meshes failed with the Nylon intermediate mesh trials, the intermediate mesh itself did not fail, only the working mesh failed. Minor wear was picked up on the Nylon intermediate mesh as shown in Figure 19, but this did not cause contamination as it appears the wires were flattened by the support mesh. Figure 19 - Nylon Intermediate Mesh Wear

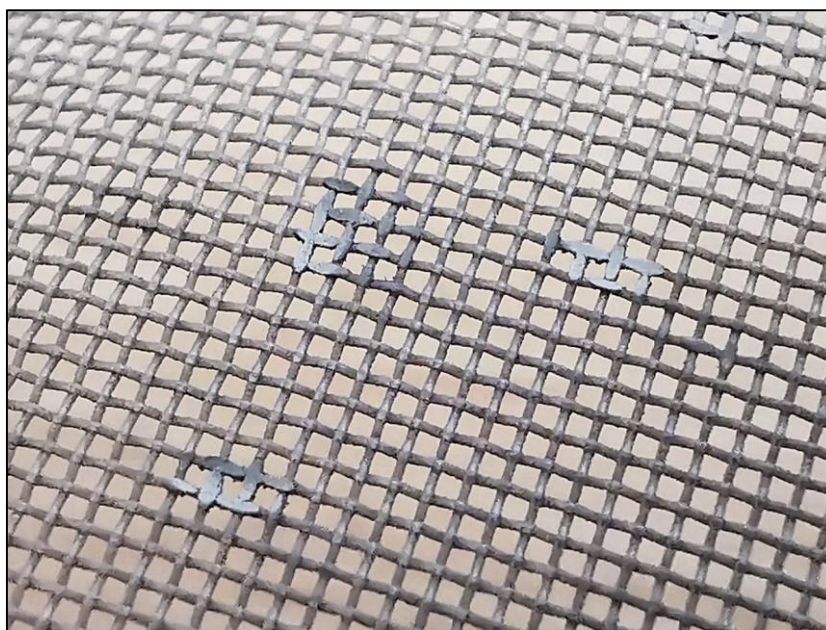


Figure 19 - Nylon Intermediate Mesh Wear

As such, Nylon working meshes cannot be used, but Nylon intermediate meshes can.

3.9.2 Mesh Replacement and Storage System

There was an issue with the savings made from using Nylon intermediate meshes that comes from production planning. Due to the way the multi-frequency sieving machine meshes are manually built, once the mesh is disassembled the same mesh cannot be reassembled as they are cut to size after being secured on the mesh frame. This means if a short run of one or two batches is planned, and a change to a different size mesh is planned directly after, the meshes are disposed of prematurely before the benefit of using the Nylon intermediate mesh is seen. In this

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case rather than saving cost due to increased tonnage per mesh, the cost is actually increased due to the use of a redundant intermediate mesh.

To prevent this scenario from having a negative impact on the cost a storage system was implemented and an investment of space mesh frames was made to allow the assembled meshes to be stored for later use if they are not damaged rather than being disassembled and wasted.

3.9.3 Changes to Process

There were some production impacts from the introduction of the Nylon intermediate meshes including:

- A small increase to the time taken to set up meshes – this was offset by the use of the storage system mentioned in chapter 3.9.3 above.
- The need for retraining of the mesh setup process – This was handled in a structured manner by the shift supervisors.
- Documentation updates including SWP, RA, and MOC – These documents were mostly updated for the trials to be carried out, so only minor changes were needed.

The implementation process progressed smoothly thanks to a structured approach.

3.9.4 Reduced Mesh Changes

The biggest positive practical implication on production is the reduced need to carry out mesh changes. Before the implementation fine meshes were failing after almost every batch and as such they needed changing once per day per sieving machine which presented a labour constraint. With the implementation of the Nylon intermediate meshes which consistently last three batches before fracturing, the need to assemble new meshes was reduced to a third.

As the meshes are used for longer, a consideration needed to be made about cleaning to prevent blinding build up from batch to batch. This meant that the sieving machines needed to be disassembled after each batch to clean the mesh, however this took less than half the time taken to assemble and install a new mesh, so there is still a time saving.

3.10 Timing Plan Update

As Trials 6-8 weren't run due to the lack of production material, there was three weeks freed up that could be used for further investigation work as shown in Figure 20.

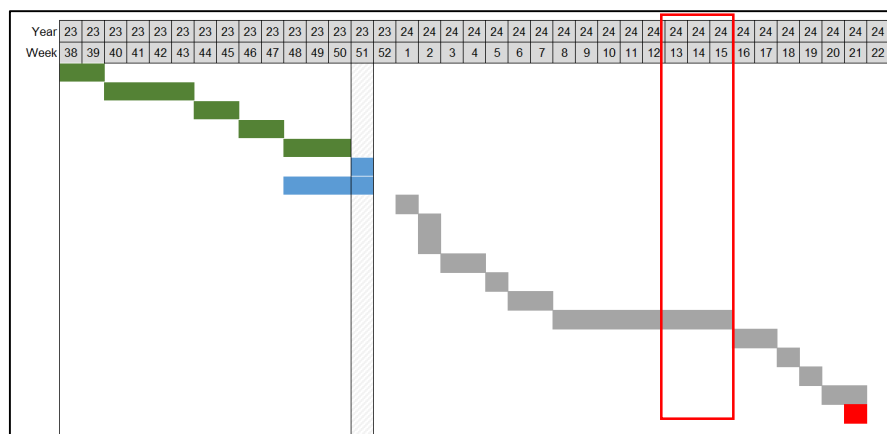


Figure 20 - Timing Plan 3 Week Gain

4. Further Investigations & Improvement Work

Even through a time and cost saving was made from the improved mesh setup, there are other considerations that effect mesh wear that were investigated as time was freed up from the reduced trial length. These other considerations didn't make as much of an improvement to the cost as the mesh setup did, however they also had other advantages.

Looking at the function of the sieving machines there are a set number of parameters than can effect mesh life. These are as follows:

- Mesh material and setup (covered in mesh trials).
- Maintenance of the sieving machine.
- Setup of variable parameters in the sieving system.
- Mesh quality.

These areas of interest have been investigated in this chapter.

4.1 Maintenance Schedules

In order to understand if the sieving machines are being maintained correctly, the manual provided by the manufacturer was checked. The following inspection and planned maintenance (PM) schedule in Figure 21 is included in the manual giving some suggestions as to what components need to be checked at what frequencies.

Component	Operations to be performed	Every day	Every 50 hours	every week	Every 200 hours/at each replacement of metal part	Every 250 hours	Each mon-th	Every 15000 hours	Every 22000 hours
Screen	Check the conditions through the inspection windows	x							
Motor vibrator	Check the noise coming from the vibrator bearings (the bearings must not produce intermittent or metallic noises).	x							
Machine	Clean the machine to prevent the formation of a layer of dust greater than 5 mm.		x						
Thread closing bars	Check the tightness with a torque wrench.	x							
Equipotential connections	Check the equipotential connections between the metal parts shown in Figure A, Figure B, Figure C.					x			
Fixing screws vibrator	Check that the screws are not loose.						x		
Buttons and cables	Condition check	x							
Metal plates for ground connection	Check the presence of the special metal plates to ensure the equipotentiality between the parts that could result.				x				
Springs	Replacement of springs								x
Bolts placed outside the screen	Check the tightness with a torque wrench.						x		
Motor vibrator fixing bolts	Check the tightness with a torque wrench.						x		

Figure 21 - Manufacturers PM Guide (Virtro, 2017)

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This was checked against the maintenance work that has been carried out which highlighted a number of gaps. When these machines were brought into the company the existing maintenance practices were carried over from the old traditional rotary sieving machines, with little thought to the different mechanism that drives the sieving machines.

The maintenance of the rotary sieving machines is a combination of Preventative Maintenance (PM) strategies, Total Productive Maintenance (TPM) strategies, and Reactive Maintenance (RM) strategies.

- PM - Visual inspection of the shaft, couplings, weights assembly, and framework on a monthly basis.
- PM - Re-greasing of the shaft bearing on a quarterly basis.
- TPM - Inspection and replacement of any meshes, flexible connections, gaskets, clips, and clamps on a daily basis by trained production operators.
- RM - Replacement and repair of all other components through the company Engineering Request (ER) system. The operators are trained in troubleshooting the systems and reporting any issues they find through the ER system, the engineering/maintenance teams see the request and can work on the problem.

This system works well for the rotary sieves, however when the multi-frequency sieves were brought in with a different operating principle and maintenance requirements, the PM's were not updated to reflect this, stock items for replacements were not set up, and retraining operators in troubleshooting and TPM's was not done. This has left the new sieving machines almost entirely to reactive maintenance, and means there are gaps where certain components are not maintained at all.

This means a revision of the maintenance system was needed, and the components that needed new maintenance procedures and practices needed to be assessed for procedures and training.

Firstly the PM guide for the sieves was updated as due to the products being processed, the existing maintenance system, and the TPM procedure system, the guide does not reflect exactly what needs to be done. The following guide in Table 5 is an adjusted version.

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Component	Operation to be Performed	Weekly	200 Running Hours/ Metal Part Change	250 Running Hours	Monthly	22000 Running Hours
Motor vibrator	Check the noise coming from the vibrator bearings (the bearings must not produce intermittent or metallic noises).	x				
Buttons and cables	Condition check. Replace if necessary.	x				
Gaskets and seals	Condition check. Replace if necessary.	x				
Tie bar hinges and threads	Condition check. Replace if necessary.	x				
Metal plates for ground connection	Check the metal plates to ensure they are earthed correctly.		x			
Equipotential connections	Check the earthing connections between the metal parts of the sieve.			x		
External bolts	Check the tightness with a torque wrench.				x	
Motor vibrator fixing bolts	Check the tightness with a torque wrench.				x	
Beater ring	Check the distance from the beater ring to the bottom of the support mesh using a blank support mesh ring and a gasket. The support mesh is 2mm thick. The gap should be 1-2mm. If the plastic material on top is in good condition, adjust with spacers, otherwise replace beater ring.				x	
Springs	Replacement of Springs.					x

Table 5 - Sandvik Multi-frequency Sieve PM Guide

This guide has been uploaded to the workplace PM system and new maintenance procedures have been updated. Following the updates all the actions in the above guide were carried out as first checks, and any adjustments needed were made.

The most important adjustment made for mesh life was the beater ring setup. The beater ring on the sieve being used had worn creating a gap of 6mm where it should be between 1-2mm. The beater rings are designed to be adjustable to compensate for wear up to a certain amount, so this was adjusted.

After the adjustment an improved sieving efficiency was seen, reducing cost. This was due to the de-blinding effect of the beater ring which reduces the effect of mesh blinding as explained earlier in chapter 2.2. There was no immediate change to mesh life seen in subsequent runs, however the need for mesh cleaning was reduced saving time and cost.

4.2 Sieving Machine Setup

4.3.1 Parameters

There are very few adjustments that can be made to the multi-frequency sieving machines. The only adjustments are:

- Mesh sizes – which are product dependant.
- Wiper gap – There are rubber wipers on the inside of the sieve which restrict the amount of powder that can flow off the mesh at a given time to increase residence time on the mesh for more efficient sieving. These are set up as per the manual and don't need adjusting as residence time is sufficient.
- Motor frequency – At default the motor frequency is set to 100% (50Hz). There is very little understanding about what altering this parameter will do to the sieve as the manual does not go into detail and no trials have been done.

This left motor frequency as the only remaining variable that could provide a benefit. As such, a short trial was carried out.

The motors have invertors attached that are locked between 42 Hz and 52 Hz and the controller is run in percentage of this range, so 0% is equal to 42 Hz, 50% is equal to 47Hz, etc. In order to test the effects of the motor frequency on the sieve performance a production trial was needed.

4.3.2 Hypothesis

As the motor frequency decreases, wear on the mesh will decrease while sieving efficiency also decreases due to less agitation force.

4.3.3 Trial

Assumptions

As there wasn't enough time left to do a full production trial and gather results, an assumption was made. That assumption is: mesh wear from motor frequency is directly proportional to the bounce height of the powder on the mesh.

Since impact force is the change in Kinetic Energy (KE) at the point of impact, it's reasonable to say the difference in KE due to height at different heights is equal to the difference in impact force. There will be a small discrepancy due to deformation of the mesh with different initial forces, but this will be treated as negligible for the sake of this trial.

Due to the relationship between KE and height, the height difference is directly proportional to the energy difference. This can be proven in the following example in Table 6 using estimated values for a 500µm particle.

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Kinetic Energy at 2cm				Kinetic Energy at 1cm			
$m = \rho V$				$m = \rho V$			
Density (ρ)	8000	kg/m ³		Density (ρ)	8000	kg/m ³	
$V = \frac{4}{3} \pi r^3$				$V = \frac{4}{3} \pi r^3$			
Diameter	0.0005	m		Diameter	0.0005	m	
Radius (r)	0.00025	m		Radius (r)	0.00025	m	
∩ Volume (V)	6.544E-11	m ³		∩ Volume (V)	6.544E-11	m ³	
∩ Mass (m)	5.235E-07	kg		∩ Mass (m)	5.235E-07	kg	
$KE = \frac{1}{2} m v^2$				$KE = \frac{1}{2} m v^2$			
$v = \sqrt{2 g h}$				$v = \sqrt{2 g h}$			
Gravity (g)	9.81			Gravity (g)	9.81		
Height (h)	0.02	m		Height (h)	0.01	m	
∩ Velocity (v)	0.626	m/s		∩ Velocity (v)	0.443	m/s	
∩ KE	1.027E-07	J		∩ KE	5.136E-08	J	

Table 6 - Calculation of Mesh Impact Force

Velocity (v) in this example is velocity due to gravity using the free fall equation. As such air resistance wasn't considered as it would be negligible.

When the height is halved from 2 cm to 1 cm bounce height, the KE value is also halved, proving that height and KE are directly proportional to each other. This relationship was used in the trial to show the change in force as the motor frequency changes.

Trial Plan

The setup for the trial was similar to the mesh trials. The same sieving machine was used with the same final setup. The product was not the same, however due to similar densities was not be a problem.

For this trial the motor frequency was altered throughout a single batch of powder on the machine and a set of tests was done to prove the effects of each change.

A 10 minute wait was done after each change to allow the powder on the mesh, and in the sieving machine to clear, ensuring the result is accurate.

The testing done was to prove whether or not there was a change to sieving efficiency, so percentage product in revert and percentage revert in product was tested after each change.

Results

Table 7 below shows the % revert in product and the bounce height off the mesh to the nearest 0.5 cm. Measuring the bounce height was difficult due to the movement of the machine as well as the speed of the bounce, so it was approximated from the distance to the viewing port, knowing the distance from the mesh to the viewing port.

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Motor Frequency (%)	% Revert in Product	% Product in Revert	Bounce Height	Comment
100	5.1	8.21	3.5 cm	Powder moving to the edge of the mesh
80	10.45	4.56	3 cm	Evenly distributed
60	4.34	4.37	2 cm	Evenly distributed
40	2.75	3.64	1 cm	Evenly distributed
20	2.83	N/A	0.5 cm	Powder sitting in the middle of the mesh

Table 7 - Motor Frequency Trial Results

The reduction in bounce height lined up with the initial hypothesis, showing that at lower motor frequencies the powder bounce height reduced dramatically, reducing the impact forces on the mesh and hence reducing the wear on the mesh.

The table also however shows that as the motor frequency decreased, so did the % product in revert and % revert in product, down to when the powder stopped spreading evenly across the mesh where the revert in product increased slightly and powder stopped going into the revert container entirely. This was because the powder began to ball up in the centre of the mesh and was no longer travelling across the mesh. As the weight of the powder built up on the mesh it forced more powder through increasing the revert in product figure. This is counter to the hypothesis, as it was assumed that more product would arrive in the revert container as it was unable to pass through the mesh.

The change in movement pattern across the mesh was a complete unknown which lead to the improved sieving efficiency. This also provides opportunities to better control the flow of material across the mesh, which could have other benefits in future.

The ideal setting given the results was 40% or 46Hz. This allowed for the best sieving efficiency while still effectively distributing the powder. At this setting the bounce height was reduced from 3.5 cm to 1 cm, reducing the wear from material impact to 29% of its initial amount.

4.3 Mesh Inspection and Standards

The meshes are manufactured to a very high accuracy on industrial looms to ensure each hole in the mesh is close to the target aperture size. In the metal powders industry very fine meshes are used, with apertures ranging from 32µm to 250µm, and as such the high standard of weaving is important to ensure the powder is cut efficiently. If the sieving process is inefficient then multiple sieving operations may be needed before enough product can be retrieved from the source material, hence increasing the cost of the operation.

Despite the high accuracy needed to weave meshes, they are still subject to manufacturing tolerances which allow a fairly wide discrepancy in the aperture size. There are two main standards that determine these tolerances, ISO 9044 (ISO, 2016) for Industrial woven wire cloth, and ISO 3310-1 (ISO (B), 2016) for test sieves. These two standards determine how much discrepancy is allowed when weaving a mesh, as well as how many minor defects is acceptable. The majority of mesh used in sieving machines is woven to ISO 9044 which is a wider standard used for mass produced mesh.

Despite this standard, the quality and accuracy of meshes can vary widely within it, and so some manufacturers produce much higher quality mesh than others through internal quality controls. These meshes are more consistent in measurement, and have a much lower standard deviation of aperture sizes within a narrower range, so their sieving efficiency is improved.

Reducing the Total Cost of Ownership of Multi-frequency Sieving Systems

Three meshes have been investigated in Figure 22 showing a difference in quality from three different manufacturers.

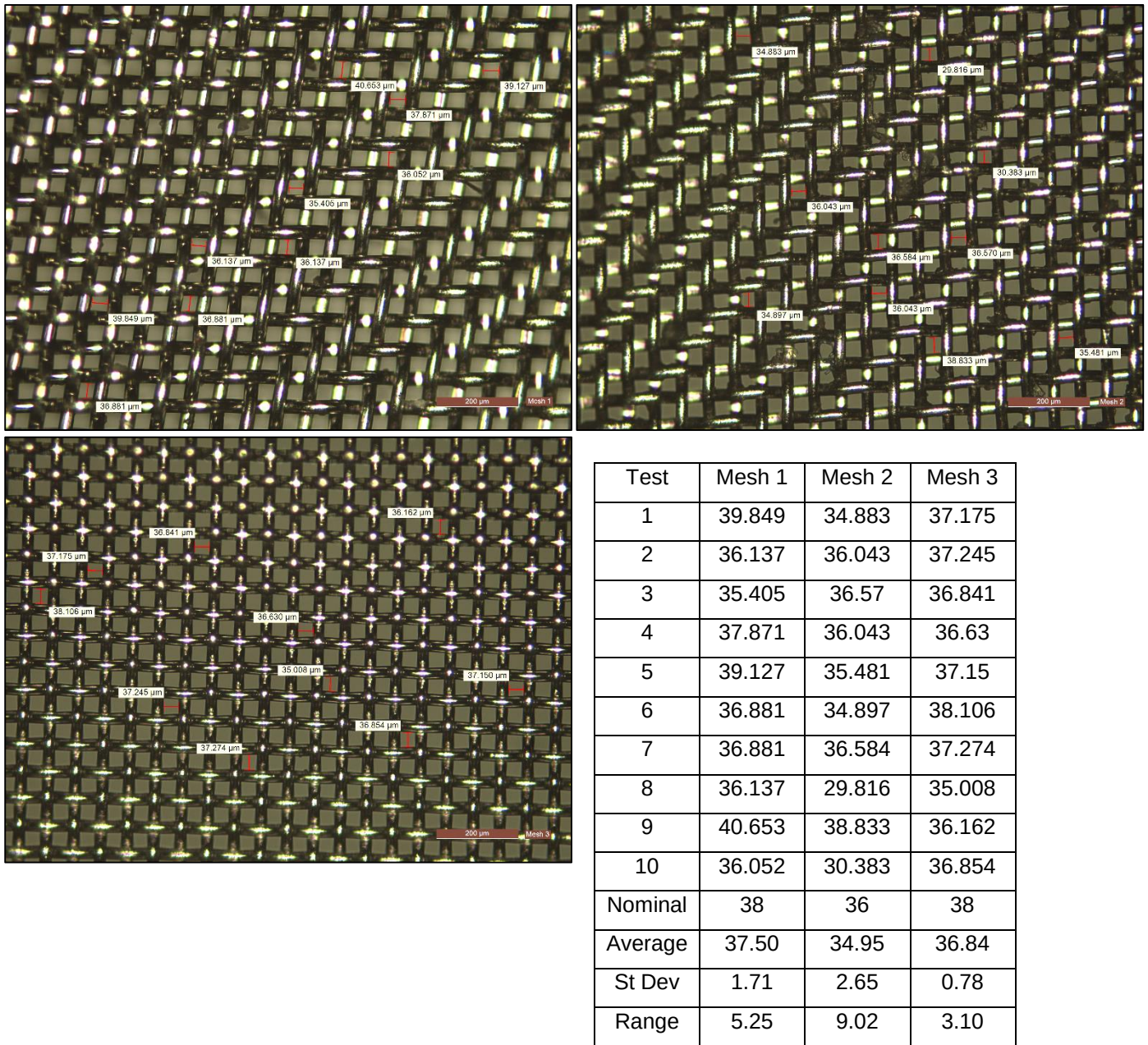


Figure 22 - Mesh Inspection Results

The three meshes pictured above are imaged on the same microscope using the same magnification and settings. They are from three different manufacturers.

It is clear from the image that Mesh 3 is the best with clean straight wires and no deformation. The apertures look uniform and equal. The data table shows a breakdown of the measurements done along with the Nominal (target) size, along with the Average, Standard Deviation (SD), and the Range of the measurements.

The SD is a key figure here, showing how consistent the mesh is. The third mesh, Mesh 3, looks the best and also has the best SD, showing it's clearly a higher quality mesh.

Mesh 1 is the mesh currently in use. Changing to Mesh 3 could prove beneficial in improving sieving efficiency further.

5. Conclusions

In conclusion to this report, the trials completed and the further work done all had positive outcomes on the TCO of the multi-frequency sieving machines. The implementation of the Nylon intermediate meshes made a massive difference, extending the usability of the meshes to a reasonable level, while the other improvements allowed for further cost gains and reliability.

5.1 Cost Implications

The biggest effect on the TCO of the sieving systems was the Nylon intermediate meshes. The expected tonnage was increased from 562kg to 3789kg per mesh, granting a 6.7 times increase in mesh life.

Introducing the Nylon intermediate meshes to the mesh setup increased the overall cost of the mesh setup by 1.6 times its original cost. This means the effective cost of the mesh setup is therefore 23.87% of the original setup, reducing the TCO to 55.12% of its original value, making the sieving machines almost half their effective cost. The new breakdown of the TCO is shown in Figure 23.

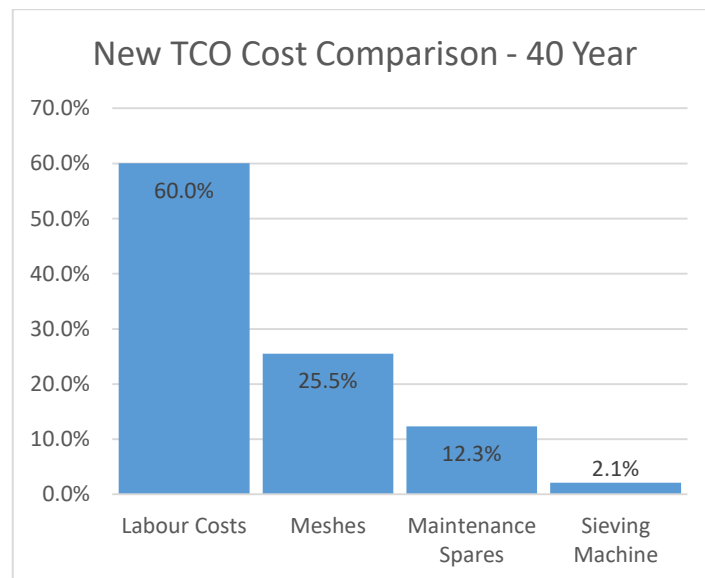


Figure 23 - New TCO Breakdown After Introduction of Nylon Meshes

The cost implications of the improved maintenance and condition of the sieving machine are hard to quantify, and are likely minute in comparison to the introduction of the Nylon meshes, however it was noted that by improving the machine condition the sieving efficiency improved, so a quality and cost gain was made.

If in altering the sieving machine motor frequency the actual wear reduction is equal to the powder bounce height reduction on the mesh then there is a potential that a large saving could be made to the TCO again as the bounce height was able to be reduced to one third of its previous value, potentially increasing the mesh life up to 3 times, gaining a similar benefit to the Nylon meshes. This would need to be proven.

5.2 Recommended further work

After the work done in this report, there is still some room for trials and experimentation.

5.2.1 Mesh Materials and Specifications

There are more options for materials of meshes that could be considered. Potentially a different synthetic mesh material, or a layup of more than one synthetic mesh could reduce the wear even further, some examples of other synthetic mesh materials are Polyester and Polypropylene which could boast superior physical properties. (Wiremesh, 2024). Using Nylon mesh with a different aperture or different wire diameter could also prove beneficial.

5.2.2 Motor Frequency Trial

Further testing of the sieving machine motor frequency could prove beneficial. Running a full trial with measured tonnage and sieving efficiencies would shed more light on its function in wear reduction and back up the theory about bounce height being proportional to mesh wear.

5.2.3 High Quality Mesh Trial

Introduction and testing of higher quality meshes, their durability, and their effect on mesh life would be a valuable study. If better meshes bought at a higher cost can increase mesh life, they can effectively pay for themselves while delivering quality improvements.

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