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1. Mills and Milling

1.1 Introduction

Mills are rugged, durable long wearing tools machined from heat treated alloy steel bar.

Hard facing and/or carbide plate cutters are then applied to the cutting blades in a manner that is designed to wear away i.e. cut, chip, grind at the object being milled in order to expose new blade cutting edges throughout the mill's life.

**Self sharpening** of the cutting blade is fundamental to milling as this will improve:

- Tool life
- Cutting time
  and
- Rates of Milling

Water courses and circulation port design also aid to ensuring that adequate cooling, lubrication and *cuttings, swarf and/or junk* removal is maintained.

A full range of standard Mill sizes are provided with optimal fishing necks, lengths, stabilisation, etc. to accommodate the most common tubular sizes.

Special mills can also be readily made available to suit any length, OD, or requirement.

Finally in today’s drilling and workover operations there is often a requirement for extensive milling operations to be carried out. To combat and meet such requirements a new generation of mills have been designed.

This manual aids to describe and illustrate an in depth view to Milling procedures and practices that are used and considered in the most commonly required applications.
1.2 General

Milling may be required during any of the following operational phases.

- Drilling
- Fishing
- Completion
- Workover
- Side-track
- Abandonment

During these phases the Milling operation is a critical procedure that must be carried out as efficiently and effectively as possible in order to minimise any operating delay, costs, and to ensure that no further problems arise.

Similar to fishing operations, each milling job is unique, the tools and techniques needed for one well may not work for another. Milling therefore requires specialised equipment, trained expertise and often trained operators from fishing equipment / service companies when specialised jobs are required e.g. section milling, milling casing, well abandonment.

There are many types of Mills and associated milling tools available, each which must be selected to best suit required operational needs, conditions and application. Milling fluid, bottom hole assemblies, stabilisation, best practices and procedures are also important aspects that must be carefully considered prior to planning or commencing any milling operation.
1.3 Guidelines for effective milling

To effectively remove the cuttings and/or junk material while milling, the following guidelines should be adhered to:

- If deemed necessary modify surface equipment for job at hand.
- Ensure a full range of tools and equipment, back ups, spare cutters and accessories are on site as required.
- Try to achieve a minimum annular velocity of 120 ft/minute.
- The flow should be turbulent if possible to prevent cuttings "bird nesting" and blocking the annulus.
- Increase the yield point of mud with a moderate increase in viscosity. Viscosity 100 + Yield point 50+
- Pump viscous pills at regular intervals.
- Always start rotating a minimum of 1 ft above fish, tubular or object to be milled.
- Adjust weight and RPM to find best milling rate. Note rotating torque.
- Mill with high RPM in excess of 100, except when milling with taper mills and washover shoes which usually operate most effectively at 75 RPM or less depending on torque.
- Try to achieve a constant milling weight. Do not allow tools to drill off.
- To maximise the life and effectiveness of some milling operations consider, picking up, working and rotating the string at regular intervals.
- Ensure all subs and auxiliary tools are full bore, if possible, to allow to allow a high a circulation rate as possible.
- If high annular velocity cannot be achieved, run one or more junk subs.
- Ensure surface equipment can sufficiently manage milled cuttings from the wellbore.
- On completion of milling flush BOP cavities.
1.4 Additional considerations

- Do not run jars while milling, this is due to the fact that weight cannot be accurately monitored and/or controlled, also spudding cannot be properly carried out.
- Prevent the mill from wobbling by stabilising it. Try however, to minimise the amount of stabilisers since they may create:
  a) excessive torque
  b) bird nesting of cuttings poor performance in certain wellbore conditions.
- Use a minimum of two to three ditch magnets at the shale shakers mud return lines. Clean these regularly and record the weight of steel recovered. **Note**: The steel is milled steel as well as casing wear.
- Run the torque and drag simulation to confirm items can be milled on rotary and determine whether or not lo-friction casing protectors are required and their placement.
- If torque and drag are predicted too high consider using a motor assembly.
- If this is not possible, fit casing protectors to string, particularly over well build up/drop-off sections.
- To minimise casing wear, add lubricants to mud, use smooth tool joints (not newly hard faced ones), and use non-rotating stabilisers when milling inside casing.
- Where the bulk volume of steel produced in milling is substantial. Appropriate preparations in a number of areas will need to be to ensure that the swarf is removed from the milling fluid disposed of as efficiently as possible.
- Pre-treating the milling fluid prior to commencement of the milling may also be required. e.g. if milling with water based muds, oil based fluids may be behind the casing, expected volumes, treatment and disposal, and containment will need addressing.

**SAFETY NOTE**: Metal swarf is pyrophoric and such can spontaneously catch fire. The metal swarf once held in containers, drums or skips should be kept damp and the rig/platform safety officers made aware of the potential fire risk.
1.5 Preparing for a Milling Job.

Before commencing a Milling operation, it is important that all aspects, options and contributory conditions effecting the job have been considered.

Among the many factors to consider would be:

- What is to be Milled e.g. size, length, metallurgical properties, shape.
- Is the object to be Milled, stabilised, rigid, free to move.
- What is contributing to the object’s condition
- What type of Mill is required
- What additional equipment may be required.
- Are there any other ways or means to remove object
- What is the well deviation, cased hole, open hole etc.
- Will conditions change when circulating.
- Is surface equipment satisfactory for job at hand.
1.6 New technology Mills

Although the mills designed in this manual are both durable and tough, due to the nature of the operations they are asked to perform their greatest disadvantages is that their operational life is short.

When significant milling operations are required, it is not uncommon for two or three mills and subsequent round trips to change the mills being required.

To combat this, increase mill life and reduce number of trips required, a new generation of mills that utilise tungsten carbide plates have in recent years been developed within the industry. These mills are both tough, durable but more important offer significantly increased longevity of the mills.

These mills are discussed in more detail in section 5 of this manual.

Figure 1.6-1: New Generation Mills.
2. Milling Junk

2.1 Introduction

Due to the milling parameters, practices and procedures utilised during junk milling operations it is extremely important that the mills are:

- Properly made and constructed
- Utilise the best materials
- Properly selected for the job at hand.

With the above criteria met, the best possible performance and results will be achieved where Junk Milling applications are required.

Three typical junk mills are illustrated below in Figure 2.1-1;

Figure 2.1-1: Junk Mills

Type A

Type B

Type C
2.2 General considerations
Junk milling is normally carried out using a specified type of *Flat bottomed mill* as illustrated in Figure 2.1-1.

2.2.1 Mill selection
The number of blades (*normally 3 or 6*), and the density and setting of the milling material used (*e.g. tungsten carbide*) must be properly selected, where selection will be based upon:

- What and how much is to be milled,
- Surrounding environment *e.g. open hole, inside casing, deviation*
- Results required.
Type A: This type of Junk Mill is suitable for all types of general Junk, as well as packers, retainers and squeeze tools. It can be provided in the following dressed diameters, connection's and fish neck sizes.

Figure 2.2-1: Type "A" Junk Mill

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Fish neck Diameter (inches)</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2 - 4 1/2</td>
<td>2 3/8&quot; Reg.</td>
<td>3 1/8</td>
<td>45</td>
</tr>
<tr>
<td>4 1/2 - 5 1/2</td>
<td>2 7/8&quot; Reg.</td>
<td>3 3/4</td>
<td>63</td>
</tr>
<tr>
<td>5 1/2 - 7 1/2</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4</td>
<td>110</td>
</tr>
<tr>
<td>7 5/8 - 9 1/2</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4</td>
<td>265</td>
</tr>
<tr>
<td>9 1/2 - 12 1/4</td>
<td>6 5/8&quot; Reg.</td>
<td>8</td>
<td>570</td>
</tr>
<tr>
<td>15 - 17 1/2</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2</td>
<td>1160</td>
</tr>
<tr>
<td>18 5/8 - 28</td>
<td>7 5/8&quot; or 8 5/8&quot; Reg.</td>
<td>9 1/2 - 11 1/4</td>
<td>2000 - 3000</td>
</tr>
</tbody>
</table>

Note: Wear pads are provided to Junk Mills to stabilise the mill this will:

- Prevent "Mill Wobble", increasing life of Mill.
- Prevent Mill wearing or cutting external tubular e.g. casing
**Type B**; This type of Junk Mill is suitable where heavier and more tortuous milling application is required, e.g. such as bit cones, roller reamer cutters and pieces from downhole tools. The density of the milling material e.g. tungsten carbide chips, will enable the Mill to chip and grind away at the milled object, with the extra depth of dressing design, ensuring as long a life as possible from the mill can be attained. The cutting face is made concave to facilitate centring the loose junk to enable more efficient and effective grinding of Junk.

**Figure 2.2-2 : Type "B" Junk Mill**

**Note**: This mill is not suited to milling in cement, as it will tend to ball up quickly.

Mills can be provided in the following dressed diameters, connection's and fish neck sizes.

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Fish neck Diameter (inches)</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2 - 4 1/2</td>
<td>2 3/8&quot; Reg.</td>
<td>3 1/8</td>
<td>52</td>
</tr>
<tr>
<td>4 1/2 - 5 1/2</td>
<td>2 7/8&quot; Reg.</td>
<td>3 3/4</td>
<td>70</td>
</tr>
<tr>
<td>5 1/2- 7 1/2</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4</td>
<td>120</td>
</tr>
<tr>
<td>7 5/8 - 9 1/2</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4</td>
<td>285</td>
</tr>
<tr>
<td>9 1/2 - 12 1/4</td>
<td>6 5/8&quot; Reg.</td>
<td>8</td>
<td>590</td>
</tr>
<tr>
<td>15 - 17 1/2</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2</td>
<td>1220</td>
</tr>
</tbody>
</table>
Type C: This type of Junk Mill was designed and suitable for light Milling, such as tubular fish, float collars, plugs, bridge plugs, and retainers. The open pattern allows for fast cutting on tubular fish, where the mill will not ball up or plug off with cement or formation. Their use is recommended where the alternative might be a steel toothed bit, since the mills will prove more durable, and will cut steel much faster. Mills can be provided in the following dressed diameters, connection’s and fish neck sizes.

Figure 2.2-3: Type "C" Junk Mill

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Fish neck Diameter (inches)</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2 - 4 1/2</td>
<td>2 3/8&quot; Pac or Reg.</td>
<td>2 7/8 or 3 1/8</td>
<td>42</td>
</tr>
<tr>
<td>4 1/2 - 5 1/2</td>
<td>2 7/8&quot; Pac or Reg.</td>
<td>3 1/8 or 3 3/4</td>
<td>58</td>
</tr>
<tr>
<td>5 1/2 - 7 1/2</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4</td>
<td>105</td>
</tr>
<tr>
<td>7 5/8 - 9 1/2</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4</td>
<td>230</td>
</tr>
<tr>
<td>9 1/2 - 12 1/4</td>
<td>6 5/8&quot; Reg.</td>
<td>8</td>
<td>500</td>
</tr>
<tr>
<td>15 - 17 1/2</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2</td>
<td>950</td>
</tr>
</tbody>
</table>
2.2.2 Specifying Mill requirements.

When ordering tools from a manufacturer it is important that the following aspects are addressed.

- Dressed diameter
- Fishing neck length and \( OD \) if appropriate
- Size and weight of casing to be run through
- Any restrictions e.g. casing hanger.
- Top connection required.

Figure 2.2-4: Mill Dimensions
2.3 Recommended practices

The following practices can be applied in most Junk Milling applications.

1. Periodically spud the mill to pound the junk down to bottom of the hole where it can be more effectively milled.
2. If torque increases suddenly then junk is alongside the mill, therefore, stop rotation, work the string and spud the mill to free the tool.
3. Never mill too long. Pick up periodically with and / or without rotation and rotate to bottom to ensure that a new wear pattern is developed and that the mill wears evenly.

2.3.1 Spudding procedure.

Spudding procedure should be as follows:

- Determine neutral point when mill is just above the junk. Make a clearly identifiable Mark on the drillstring.
- Pick up drillstring 4 to 6 feet
- Drop the drillstring, catching the string just above the neutral mark. This action causes the string to stretch and to spud mill on bottom.
- Spud 3 or 4 times turning the mill a ¾ turn between each drop.
2.3.2 Milling junk in open hole

- The mill OD should be $1/8"$ to $1/4"$ less than the open hole diameter.
- Use at least 10,000 lbs of drill collars.
- Run sufficient junk subs above the mill.

Note: Ensure that the junk sub's neck is strong enough to withstand repeated spudding.

2.3.3 Milling junk inside Casing

- Run a non rotating stabiliser above mill with the same OD as mill head.
- When spudding pick up the drillstring only 2 to 3 feet.
- OD of the mill head should be approximately the same as the casing drift ID.
2.4 Skirted Junk Mills

2.4.1 General

Skirted Junk Mills are ideal for Milling on tubular fish, e.g. cemented drillstring.

If the fish or tubing being milled is plugged, it is far better to use a shoe type guide with a flat mill, rather than assume that the flat mill on its own will not side track.

A skirted junk mill is manufactured in three of four components, readily allowing replacement of worn parts, and the facility to select the variety of flat bottomed junk mills discussed in this section.

A choice of skirts is also offered for the skirted mill using two types of wash-over shoe, as well as an overshot-type cut lip guide.

Skirted Junk mills can be provided in the following dressed diameters, connection’s and fish neck sizes.

---

Figure 2.4-1 : Skirted Junk Mill

<table>
<thead>
<tr>
<th>Skirt OD</th>
<th>Skirt ID</th>
<th>Top Connection</th>
<th>Fish neck OD</th>
<th>Inner Mill OD</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 1/2</td>
<td>4 3/4</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4&quot;</td>
<td>4 5/8&quot;</td>
<td>120</td>
</tr>
<tr>
<td>5 3/4</td>
<td>5</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4&quot;</td>
<td>4 7/8&quot;</td>
<td>140</td>
</tr>
<tr>
<td>8 1/8</td>
<td>6 3/4</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4&quot;</td>
<td>7&quot;</td>
<td>370</td>
</tr>
<tr>
<td>9 5/8</td>
<td>8 5/8</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4&quot;</td>
<td>8 1/2&quot;</td>
<td>480</td>
</tr>
<tr>
<td>10 3/4</td>
<td>9 9/16</td>
<td>6 5/8&quot; Reg.</td>
<td>8&quot;</td>
<td>9 1/2&quot;</td>
<td>500</td>
</tr>
<tr>
<td>11 1/4</td>
<td>10 1/2</td>
<td>6 5/8&quot; Reg.</td>
<td>8&quot;</td>
<td>10 5/8&quot;</td>
<td>650</td>
</tr>
</tbody>
</table>

---
2.4.2 Specifying Mill requirements.

When ordering tools from a manufacturer it is important that the following aspects are addressed.

- Dressed diameter
- Fishing neck length and OD if appropriate
- Size and weight of casing to be run through
- Id. of skirt.
- Style of skirt
- Type of inner mill
- Top connection required
2.5 Junk Milling parameters.

2.5.1 General
Parameters used during Junk Milling vary considerably and are prevalent to the conditions presented and the nature of the Junk Milling required.

The following recommendations are therefore offered only as a basis for application. They will more than likely meet the needs and requirements of the job at hand.

2.5.2 RPM Selection
Recommended RPM rates for Junk Milling can be estimated from equation 2.7-1 below.

Equation 2.5-1: RPM selection; Junk Milling

RPM Rates to gain maximum effect from the carbide

\[ \text{RPM} = \left( \text{Mill OD} \times \pi \right) \div 4000 \quad \text{(Maximum)} \]

\[ \text{RPM} = \left( \text{Mill OD} \times \pi \right) \div 3000 \quad \text{(Minimum)} \]

Example; 2.5:1: 12 1/4" Junk Milling

\[ 12 \ 1/4 \times 3.14 = 38.465 \div 3000 = 78 \text{ RPM min} \]

\[ 2 \ 1/4 \times 3.14 = 38.465 \div 4000 = 104 \text{ RPM max} \]
2.5.3 Weight on Mill

The recommended weights to be used while Junk Milling are provided in Table 2.7-2.

Table 2.5-1: Weight on Mill; Junk Milling

<table>
<thead>
<tr>
<th>TYPE</th>
<th>WEIGHT (LBS)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>4 - 12,000</td>
<td>Spud mill from time to time</td>
</tr>
<tr>
<td>Type B</td>
<td>6 - 18,000</td>
<td>Spud mill from time to time</td>
</tr>
<tr>
<td>Type C</td>
<td>2 - 8,000</td>
<td>Start Mill above fish</td>
</tr>
</tbody>
</table>
3. Pilot Milling

3.1 Introduction

Similar to any milling operations, the parameters, practices and procedures utilised during Pilot milling operations are extremely important in that the mills are:

- Properly made and constructed
- Utilise the best materials
- Selected and sized for the job at hand.

Meeting the above, will ensure that the best possible performance and results are achieved during pilot milling operations.

Figure 3.1-1: Pilot Mill
3.2 Pilot Milling; General

Pilot Mills are normally selected for milling or dressing shorter sections of tubular Junk or for dressing casing for the installation of a casing patch.

They are also excellent for milling liner hangers, and other downhole tools with a through Bore, e.g. packers, completion components, etc.

The following points should be considered when selecting and/or specifying a Pilot Mill

- Use a mill of similar diameter as the fish's drift diameter.

**Note**: Stabiliser blades should be about 1/4" larger than the OD of fish to be milled.

3.2.1 Specifying Mill requirements.

When ordering tools from a manufacturer it is important that the following aspects are addressed.

- Dressed diameter
- Fishing neck length *and OD if appropriate*
- Size and weight of casing to be run through
- Size and weight of tubular to be milled
- Top connection required

**Figure 3.2-1**: Pilot Mill Dimensions.
3.3 Pilot Milling guidelines

The following practices and procedures are to be recommended when Pilot Milling.

- Rotate above the fish to establish free rotating torque.
- Reduce RPM to approximately 30 RPM and slowly enter the fish. 
  *A Torque increase should be noted when entering the fish.*
- Apply approximately 2,000 lbs weight and stop rotating quickly.
  *Note:* A gradual slow down or spin indicates mill has entered fish and is properly aligned.
- Vary parameters to best determine optimum weight and RPM during the job.
- Once a good penetration rate has been established *do not pick up the string* but continue until the mill is worn out.

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Pilot Diameter (inches)</th>
<th>Fish Neck OD</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/4 - 4 1/4</td>
<td>2 3/8” Reg.</td>
<td>1 3/4 - 3 1/4</td>
<td>3 1/8”</td>
<td>45</td>
</tr>
<tr>
<td>4 - 5 3/8</td>
<td>2 7/8” Reg.</td>
<td>1 3/4 - 3 3/4</td>
<td>3 3/4”</td>
<td>63</td>
</tr>
<tr>
<td>5 1/2 - 7 7/8</td>
<td>3 1/2” Reg.</td>
<td>2 1/2 - 5 1/2</td>
<td>4 3/4”</td>
<td>110</td>
</tr>
<tr>
<td>7 - 10 3/4</td>
<td>4 1/2” Reg.</td>
<td>4 3/4 - 7 1/4</td>
<td>6 1/4”</td>
<td>265</td>
</tr>
<tr>
<td>9 1/2 - 17</td>
<td>6 5/8” Reg.</td>
<td>7 3/4 - 15</td>
<td>8”</td>
<td>570</td>
</tr>
</tbody>
</table>
4. Milling with a Taper Mill

4.1 Introduction

Like all milling operations, it must once again be stressed that it is vitally important that the Taper mills are:

- Properly made and constructed
- Utilise the best materials
- Selected and sized for the job at hand.

E.g. In-correct mill selection may result in excessive torque to such an extent that milling cannot be achieved.

Only meeting the above, will ensure that the best possible performance and results are achieved during taper milling operations.

Figure 4.1-1: Standard Taper Mill.

The standard design taper mill illustrated in figure 4.1-1 is ideal for milling through restrictions. The spiral blade and pointed nose making it suited for reaming out collapsed or milling through jagged or split casing, guide shoes, or can be used in enlarging restrictions through retainers and adapters.

Taper mills come in a variety of shapes, sizes and designs and can be used for a variety of requirements.
4.1.1 Mill types
Four types of Taper Mills are discussed in this section they are

A) Standard multi-purpose Taper mill
B) Conductor taper mill
C) String taper mill
D) Water Melon mill

4.1.2 Specifying Mill requirements
When ordering tools from a manufacturer it is important that the following aspects are addressed.

- Dressed diameter
- Fishing neck length and OD if appropriate
- Size and weight of casing to be run through
- Top and bottom connections as required

Figure 4.1-2: Taper Mill Specifications.
4.2 General

The nose and taper profile may be tailored to suit a specific need or milling requirement. e.g. the taper mill illustrated in figure 4.1.-2 with a flat nose would be more suited to performing a more difficult milling operation where torque reduction and allowing more weight would be required.

Taper mills are used when:

- Milling out tight spots or restriction in tubulars e.g. collapsed casing
- In conjunction with other milling and/or fishing tools e.g. Pilot milling
- Removing open hole key seats
- As a means to effectively remove “Birds Nests” of milled swarf and/or cuttings.
- Milling a window, using a whipstock or when side-tracking from within a casing string.

Finally once again stabiliser positioning is a key factor to operational performance. It’s selection and placement would be made and decided once all contributing factors have been considered. e.g. wellbore geometry, hole angle, are tubulars well cemented etc.
4.2.1 Standard Taper Mill

The standard taper mill is constructed with a dressing that is very durable, thus increasing mill life and on bottom milling duration.

The ground OD and stabiliser pads eliminate the risk of cutting out or through the outer wall of the tubular being milled.

This type of taper mill is ideally suited for cleaning out liners, tubing and/or other collapsed and deformed tubulars.

They are also used and often recommended as being used as a lead mill or placed ahead of other milling and/or fishing tools. To ensure or to clear a path free from restriction so casing, tubing milling or fishing operations can ensue. e.g. Milling out burrs, finishing off the edges of a milled casing window.

Figure 4.2-1 : Standard Taper Mill Design.

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Fish Neck OD</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2 - 4 1/2</td>
<td>2 3/8&quot; Reg.</td>
<td>3 1/8&quot;</td>
<td>45</td>
</tr>
<tr>
<td>4 1/2 - 5 1/2</td>
<td>2 7/8&quot; Reg.</td>
<td>3 3/4&quot;</td>
<td>63</td>
</tr>
<tr>
<td>5 1/2 - 7 1/2</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4&quot;</td>
<td>132</td>
</tr>
<tr>
<td>75/8 - 9 1/2</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4&quot;</td>
<td>405</td>
</tr>
<tr>
<td>9 1/2 - 12 1/4</td>
<td>6 5/8&quot; Reg.</td>
<td>8&quot;</td>
<td>880</td>
</tr>
<tr>
<td>12 1/4 - 15</td>
<td>6 5/8&quot; Reg.</td>
<td>8&quot;</td>
<td>1300</td>
</tr>
<tr>
<td>15 - 17 1/2</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2&quot;</td>
<td>1760</td>
</tr>
</tbody>
</table>
4.2.2 Conductor Taper Mills

Conductor taper mills are used to clean out restrictions in Platform, Jack up or Land rig casings.

Their design is similar to a standard taper mill, but provided with a box connection down, to facilitate installing a smaller diameter taper, Junk Mill or other pilot assembly.

Conductor taper mills can ream out considerable deformation in one pass, with their heavy set tungsten carbide dressing ensuring a prolonged life and fast cutting.

Figure 4.2-2: Conductor Taper Mill.

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Fish Neck OD</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 - 17 1/2</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2&quot;</td>
<td>1760</td>
</tr>
<tr>
<td>22 1/2 - 28</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2&quot;</td>
<td>4000</td>
</tr>
</tbody>
</table>
4.2.3 String Taper Mills

String taper mills are excellent for cleaning out damaged casing, liners, or tubing.

They are also to be recommended for removing key seats in the open hole.

The design tapers both from top and the bottom of the mill, allowing reaming operations from both directions.

The connections with pin up and box down, allow this mill to be run anywhere in the middles of a drillstring or BHA.

For removing obstructions in casing, it may be necessary to combine a smaller taper or pilot mill assembly, to avoid the risk of side-tracking off the tubular or Key seat being milling.

Figure 4.2-3: String Taper Mill

<table>
<thead>
<tr>
<th>Dressed Diameter (inches)</th>
<th>Top Connection</th>
<th>Fish Neck OD</th>
<th>Approx. weight (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2 - 4 1/2</td>
<td>2 3/8&quot; Reg.</td>
<td>3 1/8&quot;</td>
<td>45</td>
</tr>
<tr>
<td>4 1/2 - 5 1/2</td>
<td>2 7/8&quot; Reg.</td>
<td>3 3/4&quot;</td>
<td>63</td>
</tr>
<tr>
<td>5 1/2 - 7 1/2</td>
<td>3 1/2&quot; Reg.</td>
<td>4 3/4&quot;</td>
<td>132</td>
</tr>
<tr>
<td>75/8 - 9 1/2</td>
<td>4 1/2&quot; Reg.</td>
<td>6 1/4&quot;</td>
<td>405</td>
</tr>
<tr>
<td>9 1/2 - 12 1/4</td>
<td>6 5/8&quot; Reg.</td>
<td>8&quot;</td>
<td>880</td>
</tr>
<tr>
<td>14 3/4 - 17 1/2</td>
<td>7 5/8&quot; Reg.</td>
<td>9 1/2&quot;</td>
<td>1859</td>
</tr>
</tbody>
</table>
4.2.4 Water Melon Taper Mill

Similar in design to the string taper mills, the water melon mill is used in combination with other mills and drillstring components during window cutting operations. It is designed to mill up and down to provide elongation and dressing of the cut casing window.

It can also be used directly above the window mill or taper mill and is often placed 20 - 40 ft above the window mill to facilitate dressing the window while drilling the first section of formation after the casing window is complete.

Figure 4.2-4 : Water Melon Mill.
4.3 **Taper Milling guidelines.**

The following are recommended guidelines to apply while taper milling.

- Select taper mill with diameter equal to desired enlargement required.
- If particular application is in a deep deviated well, run torque drag models to assess if a lower torque taper mill profile is required.
- Always enter tubular and/or fish rotating.
- Initially use light weights *i.e.* 1,000 - 2,000 lbs. Observe torque and be aware for any torquing up and exceeding 6000 lbs and 75 RPM.
- Once the restriction has been enlarged increase speed to 80-100 RPM and rotate mill up and down through the interval several times.
5. General Operating Recommendations for Milling

5.1 Introduction

- 5K BMD mills
- String mills
- Watermelon mills

Jundi subs
non relating stabilized
5.2 *Milling Parameters.*

<table>
<thead>
<tr>
<th>TYPE</th>
<th>RPM</th>
<th>WEIGHT (LBS)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junk Mill</td>
<td>100</td>
<td>4 - 10,000</td>
<td>Spud mill from time to time</td>
</tr>
<tr>
<td>Pilot Mill</td>
<td>125</td>
<td>6 - 10,000</td>
<td>Vary weight to find best R.O.P.</td>
</tr>
<tr>
<td>Taper Mill</td>
<td>50-80</td>
<td>2 - 4,000</td>
<td>Start with light weight &amp; low RPM</td>
</tr>
<tr>
<td>Economill</td>
<td>100</td>
<td>2 - 8,000</td>
<td>Start Mill above fish</td>
</tr>
<tr>
<td>(Flat Mill)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotary Mill</td>
<td>50-100</td>
<td>2 - 6,000</td>
<td>Pick up from time to time check o/pulls and torque</td>
</tr>
</tbody>
</table>
5.3 Anticipated Milling Rates. (ft/hr)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>JUNK MILL</th>
<th>PILOT MILL</th>
<th>FLAT MILL</th>
<th>ROTARY SHOE W/OVER SHOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill Pipe</td>
<td>2 - 6</td>
<td>2 - 4</td>
<td>-</td>
<td>6 - 20</td>
</tr>
<tr>
<td>Drill Collars</td>
<td>1 - 2</td>
<td>1 - 2</td>
<td>-</td>
<td>4 - 10</td>
</tr>
<tr>
<td>Packers</td>
<td>4</td>
<td>-</td>
<td>2 - 3</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Bit Cones, etc.</td>
<td>2 - 4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>General Junk</td>
<td>3 - 5</td>
<td>-</td>
<td>2 - 4</td>
<td>-</td>
</tr>
<tr>
<td>Washover pipe/string</td>
<td>2 - 4</td>
<td>4 - 10</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
6. Packer Milling and retrieval

6.1 Introduction

In today's business there is a increasing requirement to maximise and increase the productivity and life of oil and gas fields. This has lead to an ever increasing requirement to pull existing Completions, workover the wells and/or side-track from them.

The requirement to pull and retrieve Completions more than often necessitates the requirement to retrieve production packers. This was in the past achieved in two runs, one to mill and release the packer and the second to retrieve packer assembly and/or attached completion accessories.

Knowing that time could be saved if only one trip was required to perform this operation, packer milling and retrieval tools were developed.

Three operating sequences are performed for packer milling and retrieval as illustrated below in figure 6.1.-1

Figure 6.1-1 : Packer Milling and Retrieval.
6.2 General

6.2.1 Tool components

Packer/Milling and retrieval is carried out using a packer milling/retrieval tool as illustrated in figure 6.2-1, the main components are:

- (1) Pilot Milling Head
- (2) Extension sub
- (3-7) Catch assy - catch sleeve, retaining ring and shear sleeve
- (11) Bottom mill

<table>
<thead>
<tr>
<th>Part number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pilot Millhead</td>
</tr>
<tr>
<td>2</td>
<td>Extension sub</td>
</tr>
<tr>
<td>3</td>
<td>Retaining Ring</td>
</tr>
<tr>
<td>4</td>
<td>Catch Mandrel</td>
</tr>
<tr>
<td>5</td>
<td>Retaining ring screws</td>
</tr>
<tr>
<td>6</td>
<td>Spring</td>
</tr>
<tr>
<td>7</td>
<td>Catch sleeve</td>
</tr>
<tr>
<td>8</td>
<td>Shear pin ret screws</td>
</tr>
<tr>
<td>9</td>
<td>Shear pin</td>
</tr>
<tr>
<td>10</td>
<td>Shear sleeve</td>
</tr>
<tr>
<td>11</td>
<td>Bottom Mill</td>
</tr>
<tr>
<td>12</td>
<td>Dual catch mandrel</td>
</tr>
</tbody>
</table>

Figure 6.2-1: Packer milling tool components.
6.2.2 Specifying Packer Milling requirements

When ordering tools from a manufacturer it is important that the following component aspects are addressed.

- Complete assembly number
- Size and weight of casing to be run through
- Make, type, size and ID of packer to be milled
- If a dual catcher is required.

Recommended spares.

- 1 retaining ring, three sets of retaining screws
- 1 spring.
- 3 sets of shear pins
- 3 sets of shear pin retaining screws
- 2 catch sleeves

Figure 6.2-2: Packer Milling tool.
6.2.3 BHA considerations

The packer milling and retrieval tool is run in conjunction with junk subs and non-rotating stabiliser, a circulating sub being also run in the BHA.

A standard Packer Milling BHA would consist of:

- Packer milling retrieving tool
- 2 or 3 junk subs
- Non rotating stab
- Circ sub
- DC's sufficient to provide up to 25,000 lbs Weight on the mill.

Figure 6.2-3: Packer milling BHA.
6.3 Preparation

Install a drillpipe wiper over the hole when RIH and POOH. 
*This prevents debris from dropping on top of the packer*

Ensure tools are fully checked, dimensions taken and serviced at surface prior to running.

- Check the shear pin nut has been fitted the correct number of shear pins
- Check catcher mechanism is free to move up against the spring and that the spring is not cracked or damaged.
- Check the spring holding ring is tight

In highly deviated wells where high torque values have been experienced or are indicated by torque drag simulation.

- Perform a torque and drag simulation to confirm that the packer can be milled on rotary and determine whether or not torque reduction measures are required, *i.e. lo-torque casing protectors and as to where they should best be placed.*
- If this is not possible, fit casing protectors to string, particularly over well build up/drop-off sections.
- Check protectors to ensure they are not worn and that pins are secure, any protectors that drop off on top of the packer will have to be fished.
- Consider using a mud motor to drive the milling assembly or to replacing the wellbore fluid to oil mud.
- As the pilot mill is likely to back off due to the whip when it breaks free, a two trip operation should be considered, *i.e. a separate trip made to fish the packer after milling.*
6.3.1 Making up packer picker assembly - assembly checks.

a) Space Out; Space Out of Packer Picker Dimension B must not exceed dimension A (the mill out extension length).

Even if the small clean-out mill is smaller than the seal-bore protector ID, the chance should not be taken to include this mill passing into the seal-bore protector as junk or debris during the milling operation may get trapped inside the tailpipe and be trapped at this reduction in ID between mill-out-extension and the seal-bore protector. i.e. the packer picker will be able to mill the complete packer length dimension C before the small clean-out mill has reached the end of the mill-out extension.

b) Assembly is packer picker c/w correct length of spaceout mandrel, three junk subs, soft blade or non-rotating stabiliser and circulating sub (refer to illustration of typical packer picking/milling assembly).

This complete assembly is made up on the catwalk, saving time on the rig floor. A home-made assembly to clamp the small clean-out entry mill is placed into the 4 rotary bushing pins and the assembly torqued up.

c) Check the shear pin nut has been fitted with all the shear pins, each shear pin has shear rating of 12,000 lbs.

Always fit maximum number of shear pins i.e.

- 9 5/8" tool 10,
- 7" tool 8.

Thus to shear assembly off from packer, requires 120,000 lbs and 96,000 lbs overpull for 9 5/8" and 7" packers respectively.

d) Check catcher mechanism is free to move up against the spring and that the spring is not cracked or damaged. The spring holding ring is checked for tightness.

Note: Recovery should preferably be with a release and collet type latch mechanism for which a mill-out extension is required in the packer assembly.
Milling Practices and Procedures.

e) The finger catch mechanism should be taped up completely with string parcel tape - *this prevents any small pieces of junk or debris jamming between the slots of the fingers and possibly preventing the catching mechanism from operating properly.*

It has been seen before that small pieces of junk which have caught between the slots have bent the fingers inwards making catching of the packer impossible. The tape also prevents any debris entering the slots when the assembly is run.

f) A 4-bladed main packer mill should always be used if a choice is available. These mills should always be used when milling full bore permanent packers, as when using skirt type mill (burning shoes) problems may occur circulating junk above the mill due to the restricted flow area.
6.3.2 Operating procedures.

RIH to 30 ft above packer. Break circulation to ensure mill ports are clear and record drags and rotating weight.

Enter packer with pilot mill and catcher, check engagement of catcher with 25,000 lbs overpull.

Mill on packer Parameters quoted for a 9 5/8" casing packer with:

- 10-25 WOB,
- 250-450 GPM,
- 80-100 RPM.

Whilst milling a packer,
- Pump 20-40 bbl hi visc pills every 30 minutes.

When packer free
- Flow check and observe well.
- Work string and junk subs.

POH, limiting overpulls to below shear ratings of shear sleeve. (120,000 lb - 9-5/8" tool, 85,000 - 7" tool). Be aware of possible swabbing.

Recover packer and tailpipe assembly.
Milling Practices and Procedures.

If packer not recovered then;
Make up the following fishing assembly:

- Spear c/w mule shoe,
- non-rotating stab,
- circ sub,
- bumper sub,
- jar
- DC’s.
- Accelerator etc.

Normally the catcher sleeve assembly will be run beneath the Bowen Itco spear to provide a double catch facility.
6.3.3 General Notes

The milling heads can be either 3 or 4 bladed, where possible use the 4 bladed type as milling time is normally reduced and size of mill cuttings is smaller.

Note: Average milling time with the 3 bladed on 9-5/8" packer is 5 hrs.

If there is junk on top of packer then whilst circulating work tool in using pilot mill and check periodically for engagement of catcher.

The catcher sleeves also vary in design by way of slot length, where possible use the catcher which has the shorter slot length.

Where large amounts of LCM have been use the catcher sleeve has is likely to become clogged with LCM and may jam in the release position. If in any doubt, prior to running the tool, tape up the catcher sleeve to prevent any junk/LCM from lodging behind the catcher sleeve.

When the packer is freed losses may re-occur to the well.

When POH overpulls can be expected when pulling packer past casing collars - limit overpull to be between 40-60,000 lbs.
7. Casing Milling.

7.1 Introduction
Recent operations in the North Sea during the last decade have shown that operators can successfully mill large sections of casing.

The lessons learned and techniques developed are presented within this section.

7.2 General
Casing Milling is the term given to milling substantial, long sections of casing, following retrieval of the un-cemented casing string above the cut point.

This has been performed typically on platform wells, where the existing well has been abandoned, across the reservoir. The remaining portion of the well has been utilised to allow a new well to be drilled when no further slots have been available on the platform.

Long sections of cemented casing have been successfully milled using the new range of casing mills available e.g.

- **1726 ft of 13 3/8" 72 lb./ft casing**
- **909 ft of 9 5/8" 47 lb./ft casing**

Figure 7.2-1 : Casing Mill
7.3 Selection of Casing Milling Interval

7.3.1 General
Once an interval has been determined, a number of points would be considered:

1. Well status
2. Casing string tally
3. Positioning of casing centralisers
4. Annular fluid behind casing
5. Mud contamination
6. Torque and drag.
Start of milling operation

After milling for an extended period of time
7.3.2 Interval guidelines for selection.

1. **Review well status** prior to casing milling operations.
   - **Consult cement bond or calliper logs** to assess the degree of casing, cementation and condition over the casing section to be milled.
   - **Review wellbore survey data** if available.
     This can have a profound impact on the BHA design requirements.

   Mechanical performance will be improved across well cemented intervals where lateral play is minimised.

2. **Consult casing string tally** to establish position of casing collars and casing jewellery.
   - The section to be milled should start either 5 ft above or 15 ft below a casing collar to avoid the casing backing off from the coupling.
   - Plan to mill as few casing collars as possible and finish the milling above a coupling.

   Couplings typically contain 80 - 120% more steel per unit length than casing and will rapidly wear cutting blades.

3. **Avoid having to mill centralisers.** If this is unavoidable, plan to mill the centralisers at the beginning of the section before the blades are dulled.
   The potential for tool damage in increased by the lack of restraint on centralisers and stop collars being able to spin around the casing. Also they tend to break into larger pieces and can be difficult to remove.

4. **Establish contents of annular fluid** and consider relevant mud weights for section previously drilled, along with pore pressure, formation integrity and possible zones for potential communication.

5. **Consider contaminating effect of annulus fluids and selected milling fluids** and required steps to be taken.

6. **Consider the ability to effectively rotate the string and apply milling torque** should be assessed by reference to a drilling simulator programme (inputting milling fluid, drill string and well trajectory data).

   The high frictional forces in deep or highly deviated wells may dictate the use of well lubricated muds.
7.4 Swarf, steel cuttings and solids removal.

7.4.1 Optimal performance

Before commencing any casing milling operation, there are key points that must be considered if optimum performance is to be achieved, they are;

1. Effective downhole milling mechanics
2. Efficient swarf, cuttings, and solids removal.

Note: Either aspect may prove the key element that will effectively limit the net rate of progress.

Example: When milling 500 ft of 13 3/8" 72 lbs/ft casing 35,000 lbs of swarf will be generated. This will fill 17-20 skips.

It can appreciated that the effectiveness of the operation will depend largely on how such quantities of swarf material is handled by the surface equipment (that has been designed for drilling) and how it is transported into the waste containers or skips available.
7.4.2 Milled cuttings handling

It can be appreciated that the volume of steel produced in milling large sections of casing is substantial.

The effectiveness of the operation depends to a large extent on how this material is handled on surface. i.e. The surface riser, equipment and cuttings removal system and their location.

Prior to commencement of milling operations, appropriate preparations in a number of areas need to be considered to ensure that the swarf is removed from the milling fluid and disposed of as efficiently as possible with the intent of achieving the following aims;

1. Provide a safe working environment.
2. Ensure that there are no surface traps that will collect steel cuttings.
3. Ensure cuttings are removed efficiently with ease of handling
4. Ensure that any "Birds nest" pumped out the hole can be safely and effectively removed at surface.
5. Ensure that all cuttings are removed from the mud prior to returning to the mud pits.
7.4.3 Other handling/removal considerations

The swarf produced by milling at rates of 20 ft/hr has been effectively handled for several hours without interruptions, however well designed surface facilities are essential to sustain such progress.

The likelihood and probable severity of hole cleaning problems or of blockages on surface must increase at higher milling rates. The most cost-effective rate lies somewhere the maximum rate at which steel could be cut and a rate at which progress is virtually continuous.

Day rates and the cost/contribution of surface modifications must therefore be included in the assessment.

Returns to the header box should be top dumped.

Don't rely on efficient use of magnets. Screening of mud float has proved to be much more effective.
7.4.4 General Handling guidelines.

For large sections and significant volumes.

1 Ideally the majority of the swarf circulated from the well will be removed in a gumbo box arrangement situated close to the bell nipple.

However, as this facility will not be available in most cases, the routing through the primary solids control equipment will be crucial, especially the elimination of undesirable swarf traps.

2 All internal restrictions and instrumentation, metering devices, etc. should be removed from the flow line.

Sections with potential for swarf build-up and blockage may need to be temporarily substituted with open trough sections. Suitable access points for rodding, jetting or flushing the flow line in order to disturb blockages should be provided. Facility to jet the flow line may be useful - temporary connection from header box jetting line?

3 Returns should be directly feed into the top of shaker header boxes, i.e. "top dumped". If practical, the lower regions of the box should be plated off so that the swarf "flows" with the mud to the shakers and does not build up in the sump. Do not seal off the sump completely as draining through the dump valve may be necessary at some stage.

4 The arrangement for managing flow to the shakers may need attention. Thule shakers have gates which lift up to open a slot and perforated guide plates, both features tend to trap swarf and cause it to build up. If not cleared then minor collections of swarf can become major accumulations quite quickly. A weir arrangement is recommended in place of the gates and the perforations should be covered with thin steel plate.

5 Swarf will tend to bind in the mesh of coarse shaker screens. The finest mesh sizes robust enough to withstand the duty should be established quickly. It should be practical to use 40 or 60 mesh screens on top and 80 or 100 mesh on the bottom.
6 If the cuttings disposal chute is relatively straight, or has a large bore and convenient intersection point, it may be a practical means of transporting swarf away from the shakers. However, be cautious: a blocked chute can be difficult to clear. A means of getting the swarf from the chute and into skips, and for the regular changing of skips must be devised. A builder's rubbish chute (plastic sections wired together, say 14" minimum ID) is a good example of getting the collected swarf into the skips placed on a lower deck.

7 SAFETY NOTE: Metal swarf is pyrophoric and as such can spontaneously catch fire. The metal swarf once held in containers, drums or skips should be kept damp and the rig/platform safety officers made aware of the potential fire risk.

8 As a guide to the number of skips required, allow 5 - 6,000 lbs of in situ casing steel per skip e.g. 106 - 127 feet of 47 ppf 9 5/8" casing.

The bulk volume will vary with the form of swarf cut, a skip may be physically full before the allowable load is reached. Weigh a 3/4 full skip on the crane to test the actual situation. Obviously sufficient skips will be required to complete the job or sustain operations until the next scheduled arrival of a supply vessel. As a minimum, maintain sufficient skips on board to sustain 4 days milling.

9 Grating filters or traps "Beaver traps" should be placed over drains in the vicinity of the shakers to prevent swarf entering and blocking the lines.

Simple steel baskets with grating/mesh panels should be fabricated for installation in the mud return lines immediately downstream of the shakers and in the pit room to strain the flow for small pieces of steel. Ditch magnets should also be positioned in both locations, in pairs. If the facility is available, then mud pump suction strainers should be used - sized for the largest tolerable drop in delivery charge pressure. Strainers and magnets must be checked and cleaned frequently by organising a planned cleaning schedule.

It should be noted that during milling 1700 ft of 13 3/8" casing using the above screening methods, NO PUMP FLUID END PARTS required changing.
10. Milling of long sections of casing results in large transfers of heat energy into the milling fluid - high temperatures can be expected (e.g. 180 deg.F while milling at 5600' TVD in a central North Sea well).

Efficient fume extraction and ventilation in the shaker/header box area is required if tolerable working conditions are to be maintained. Examine the practicality of improving the natural ventilation by installing louvers or temporarily opening up sections of walls.

11. Small rakes with round-ended tines assist in moving swarf off the shaker screens. Shovels and potato digging forks will be required for manual handling of swarf.

12. Cleaning points should be established at locations where swarf can build up and where mud spillage's may occur.

13. The wear bushing profile should present a smooth bore through the wellhead to avoid any tendency for swarf to become trapped and build up.

14. Unnecessarily functioning BOPs or circulating through additional equipment and valves should be avoided in order to minimise potential damage by swarf to seals and seal areas.

15. In the interests of subsequent equipment and drilling fluid maintenance, it is important that all remaining pieces of milled swarf be removed from the surface facilities on completion of operations.

The mud pumps, lines and valves should be fully inspected. In addition to mud lines and pits, this should include the drip tray, trip tank, areas around and under the shakers and places forming natural traps. BOP ram cavities, kill and choke lines, standpipe and choke manifolds should be flushed.
7.5 Hole cleaning/ milling fluids.

Successful milling depends upon the swarf, steel cuttings, solids, and/or junk being efficiently removed from the well. The procedures adopted must ensure that the formation of birds nests is avoided.

You can only mill as fast as you can clean the hole.

7.5.1 Annular velocity / Fluid properties.

The most important criteria for hole cleaning above all others is the annular velocity and the properties of the milling fluid. At this time, there are no full guidelines available on pump rates, hole inclination and mill rates as there are for drilling. However, individual cases can be addressed.

However the milling assembly must be designed to minimise pressure loss. Design must therefore centre on maximising flowrate.

Figure 7.5-1 : Minimum flowrate guidelines.

- 900 - 1000 GPM + milling 13 3/8“ casing
- 650 - 850 GPM milling 9 5/8“ casing
- 550 - 650 GPM milling 7“ casing / liner
7.6 Mud System - Selection of Mud Type

The selection of mud type must take account of the following criteria:

- **Surface handling system for swarf removal** *(personnel contact and PPE aspects.)*
- **Downhole torque** *(check drill string simulator.)*
- **Material behind the casing to be milled** *(requirement for shale inhibition etc.)*

It should be pointed out that the loss of large quantities of mud over the shakers is expected when carrying out extended milling operations.

With the unusually high degree of personal contact associated with surface handling with the drilling fluid in use and although protective gear is used. Standards of housekeeping will quickly deteriorate.

Oil muds under such circumstances will rapidly create a more unsuited working environment and conditions more so than water based muds.

Hence water based muds are to be preferred for use in extended milling operations. They are cheaper, but more importantly much easier to handle during such operations than oil based muds.
7.6.1 Oil Based or Water Based Mud

In general, if more than a few days milling are planned, it is recommended that water based fluids are used.

During the milling operation, due to the high degree of personnel contact involved with the fluid and handling of cuttings, clearing birds nests, collecting and disposing of the swarf etc. Operationally the working environment is far from ideal. Even with the appropriate protective clothing, use of an oil based mud will inevitably result in increased levels of skin complaints, spillage's loss of mud on cuttings and increased mud costs.

7.6.2 Water Based Mud Types

If a water based fluid is used, then consideration must be given to possible shale inhibition requirements if the operation will expose the milling fluid to water sensitive formations.

In general, if the formation was previously drilled with oil based mud, a non-inhibitive water based mud can be used as the near wellbore formation will be oil saturated. If the formation was previously drilled with an inhibited water based mud, then an inhibitive milling fluid will be required.

There are several types of water based milling fluid that can be used. These include:

- **Bentonite/XC Polymer**
- **Bentonite/Sodium Bicarbonate**
- **Bentonite/Mixed Metal Hydroxide**

These are basic systems with no shale inhibition properties. If shale inhibition properties are required, specific advice should be sought.
7.6.3 Mud Properties

7.6.3.1 Mud Weight

When possible an un weighted system should be applied if a water based mud is in use as this will greatly assist logistics. When milling casing across open hole, the mud weight should be that as used to initially drill the section.

7.6.3.2 Rheology

The most important characteristics of the fluid from swarf lifting consideration is its low shear rate rheology. This defines the viscosity of the fluid at the shear rate it experiences in the annulus.

This is best expressed as the yield stress of the fluid, defined as:

\[(2 \times 3 \text{ rpm reading}) - (1 \times 6 \text{ rpm reading})\]

The following rheological criteria are given as a guideline:

Figure 7.6-1 : Recommended mud properties.

<table>
<thead>
<tr>
<th>PV</th>
<th>cP</th>
<th>&lt;10</th>
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</thead>
<tbody>
<tr>
<td>YP</td>
<td>lbs/100 sq ft</td>
<td>50-70</td>
</tr>
<tr>
<td>Gels</td>
<td>lbs/100 sq ft</td>
<td>35-50</td>
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<tr>
<td>6/3 fann values</td>
<td>25 / 23</td>
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</tbody>
</table>

* With oil based mud, it will be impossible to achieve the above low plastic viscosity criteria.
7.6.4 Mud Contamination

Mud contamination by cement from behind the casing may require substantial additions of Sodium Bicarbonate to treat the presence of excess Ca ions.

A large quantity of sodium bicarbonate should be available offshore as a contingency if required.

Consideration to pre-treating the milling fluid prior to commencement of the milling may also be required.

Should oil based fluids be behind the casing, the expected volumes, treatment and disposal, and containment will need addressing.
7.7 Milling Assembly

High steel cutting rates and long mill life cannot be achieved unless the mill:

- Runs smoothly,
- Is properly stabilised
- Is prevented from off centre loading
  *i.e. eliminating mill wobble and BHA selection is therefore essential.*

Many factors must therefore be considered when selecting the best suited BHA for the job at hand. e.g. A well stabilised (too stiff an assembly) may not follow the desired wellbore path, resulting in inefficient and slow milling. Too flexible an assembly may expose the mill to too much wobble and vibrational effects that will in turn significantly reduce mill life.

The following assembly proved very successful in milling 9 5/8" casing within a deviated wellbore.

*i.e. 908 ft milled in 59 rotating hrs, Blades 40% worn :*

Figure 7.7-1: Typical 9 5/8" casing milling assembly.

8 1/2" Taper Mill; 8 1/2" Near Bit Stab; 8 1/2" String Stab; XO;
10 3/4" Casing Mill; 10 3/4" String Stab
3 * 8" DC; Jars; 8" DC; XO; * HWDP.
7.7.1 Casing Milling, BHA considerations.

1. The components of the pilot assembly (below the mill) should be the same size as the casing drift size.

2. The OD of the casing mill (Barracuda/Piranha etc.) blades should be slightly larger (up to 1/4" greater) than the casing couplings.

3. The stabiliser above the casing mill should have the same OD as the dressed mill blades.

4. Stabiliser blades should have an open spiral design to allow cut swarf to pass freely.

5. Sharp lead-ins at the start of the blades should be avoided.

6. Limit the number of drill collars to that required to provide the maximum weight of the mill planned.

7. There is a real danger of the connections below the casing mill backing out with consequent loss of all or part of the pilot assembly.

8. It appears that some of the steel cuttings do fall downhole and can form a bridge. This could result in having to fish a lost assembly in order to allow access for the next milling assembly.

9. Use "lock-up type" connections if available for the pilot assembly, otherwise connections should be made up "dry", use of a thread-locking compound should also be considered.

10. It is preferable to having the string stab - XO - casing mill section of the assembly made up onshore and shipped out as a unit.

11. Loss of the pilot assembly will cause the mill to wobble or run rough; indicated by uneven drill string behaviour, erratic torque and reduced rate of progress. The blades become worn in a tapered fashion as the tool is not centralised on the casing stump.

12. Monitor quality of cement (if any) returning at the shakers. This will indicate if casing is well cemented.
7.8 Operating procedures.

As with any downhole tools, ensure that all lengths and dimensions have been measured before the assembly is run.

Also confirm that suitable fishing tools are available.

1. Space out the string, if necessary, so that no connection is required during the initial stages of the operation.

2. Lower the assembly to about 5 feet above the top of the casing.

It is advisable to record all available information to assist in evaluation of the situation if downhole complications develop

- Check static and rotating hole drags and the free rotating torque.
- Record pump pressure at the planned operating flowrate and also at a reduced rate (say 50%).

3. If it is necessary to tag the casing, be sure whether it is the taper mill or the casing mill which is taking weight.

Enter the casing slowly rotating with the pilot assembly

- It may be necessary to work the taper mill for a short time to establish clear access.

4. Once entered increase rotation (80 - 100 rpm) with the casing mill blades above the top of the casing and slowly run down to touch it with minimum weight.

Regard casing milling as a machining type operation; allow the mill to cut its profile before increasing rotary speed and weight. Continue at a moderate milling speed (up to 6 ft/hr, say) for some time to establish that the milled cuttings and swarf are being removed from the hole in appropriate volumes.

5. Optimise rotary speed and weight for each job, and run to be made. Experiment systematically to find the parameters which result in smoothest running and best rate of progress.

As a guideline Rotary speeds of up to 180 rpm and 4 - 8,000 lbs WOB will likely be most effective.
6 Allow the draw works brake to "creep off" evenly while maintaining a steady weight should be the objective, avoid allowing the weight to drill-off.

Difficult to achieve on a disc brake system.

7 Increase milling rates only when satisfied that the hole is being cleaned effectively and that the volume of swarf can be handled on surface.

8 Unless there is evidence that hard cement is taking a significant portion of the load, then the milling weight would not be expected to exceed 10,000 lbs (less for K55 grade material).

Slower rotary speeds should prolong the life of the mill when cutting P110 or harder grades of steel.

9 Mark the pipe at the rotary table in 1' intervals and record milling data on trend sheet for each increment as the job progresses.

10 Increase in pump pressure are the first indicator of a hole cleaning problem, swarf will aggregate and pack-off the annulus in a downhole "birds nest".

Reductions in swarf volume at the shakers suggest a near surface accumulation or blockage.

11 Pump pressure increases may be small (less than 50 psi) or so large that the pumps have to be slowed or even stopped.

Cease milling and work the string to attempt to clear the birds nest. If the nest is in the riser, a means of disturbing it is to pull back far enough so that a stabiliser can be made up into the string and then worked down to the wellhead. If a top drive is used, then a stand with stabiliser at the bottom should be racked to save time in picking it up.

12 Removal of a nest around the drill string at the bell nipple will require some form of grab or a barbed rope spear to be available for running on a drill floor tugger.

13 Pumping a hi-vis pill after each casing coupling has been milled is recommended. If the flow line is prone to blockage, then it may be advisable to stop milling and flush or rod it periodically before it blocks completely.
14 Casing couplings will mill more slowly and may require rotary speed or greater weight.

Most non-integral couplings are not threaded to the very end, as a result the unthreaded portion breaks free as the mill blades approach the lower end of the coupling. The loose ring may break up or become trapped and milled, however it may also start to spin on the top of the remaining casing at any stage, preventing the mill from biting. If this occurs then gentle spudding on the ring should cause it to break up or become distorted and trapped so that it can be milled up. Stop rings and centralisers can cause a similar result and should be treated accordingly.

15 If drill string is bouncing or rough running starts to occur, then the weight and rotary speed should be reduced for a while before attempting to gradually increase the parameters again.

16 Poorly cemented casing may necessitate lower rotary speeds with less applied weight.

17 Milling through badly damaged casing may be problematical and should be avoided if possible.

If unavoidable, then swedging and/or internal dressing may be required to prepare the casing prior to milling. Tearing or splitting of severely corroded casing should be minimised by high speeds and light weights.

18 On completion of milling, a flat-bottomed junk mill assembly should be run to clean up any debris remaining above the casing stump.

Milling of 13 3/8" casing may result in leaving of a cement sheath from the former annulus. It may be necessary to remove this sheath after each mill run to minimise the risk of blocks collapsing in on the BHA. The relatively thin sheath around 9 5/8" casing in unlikely to be self-supporting and should be less of a problem.
8. Section Milling.

8.1 Introduction.

Section Milling is the term given to removing a section of casing, usually cemented, without disturbing the casing string above in "cutting a window". A typical window would be a cut casing interval ranging from 60 to 100 ft.

The window can then be used as an exit point to allow a new hole section "side-track" to be drilled by kicking off through the window.

The tools used are commonly known as "section mills" although they are also used effectively in cutting casing strings prior to retrieval.

Optimum progress relies on

- Good downhole milling mechanics
- Mill cutting characteristics
- BHA
- Operating parameters
  and
- Efficient removal of the milled steel cuttings, or swarf.
8.2 General

The cutting of a window will produce substantial volumes of swarf, the removal of which will require planning to ensure efficient hole cleaning and effective collection and disposal on surface.

Section mills are less robust and have much less cutting structure than casing mills; steel cutting rates will be lower and run lengths very much shorter. However, the form of swarf cut may be finer, less spiralled, and consequently less prone to tangling.

These factors influence the selection of milling fluids and determine the extent of modifications justified in the surface handling facilities. Although the emphasis may be less critical than for casing milling, the principles remain valid and proper planning should not be overlooked.
8.3 Selection of Window interval.

Once the approximate position of the window has been determined, a number of points should be considered in determining the exact interval.

1. **Well status** prior to section milling operations. Consult cement bond logs to assess the degree of casing-cement bonding over the casing section to be milled. Mechanical performance will be improved across well cemented intervals where lateral play in minimised.

2. **Casing string tally** should be reviewed to establish position of casing collars and casing jewellery. The section to be milled should start either 5 ft above or 15 ft below a casing collar to avoid the casing backing off from the coupling. Plan to mill as few casing collars as possible and finish the window above a coupling. Couplings typically contain 80 - 120% more steel per unit length than casing and will rapidly wear cutting knives.

3. Avoid having to mill **centralisers** if possible. If this is unavoidable, plan to mill the centralisers at the beginning of the section before the knives are dulled. The potential for tool damage is increased by the lack of restraint on centralisers and stop collars being able to spin around the casing. Also they tend to break into larger pieces and can be difficult to remove.

4. **Establish contents of annulus fluid** and consider relevant mud weights for section previously drilled, along with pore pressure, formation integrity and possible zones of potential communication.

5. **Consider effect of annulus fluids** in contaminating selected milling fluids and require steps to be taken.

6. The ability to effectively rotate the string and apply milling torque should be assessed by reference to the drilling simulator programme input milling fluid, drill string and well trajectory data. The high frictional forces in deep or highly deviated wells may dictate the use of well lubricated oil muds.
8.4 Section Mills, Tools operation.

A typical section mill tool is shown opposite along with its basic design and operating principles. Tungsten carbide coated knives are hinge-pinned to the tool and are hydraulically actuated to make contact with, and abrade, the casing well.

Depending on its size and design, the section mill generally has 3 or 6 knives. The basic operating principle is similar to that of an under reamer.

A downward force is created by the pressure drop in the circulating fluid as it flows through an interval nozzle of orifice.

The force acts upon a simple piston/cam arrangement to open out the knives until they are wedged into contact with casing wall.

The maximum cutting circle diameter is fixed by selecting knives of the required length or by setting a stop to limit the opening travel of the knives.

Once opened, most tools allow a portion of the fluid flow to bypass the nozzle or even directly onto the face of the knives.

The consequent reduction in pressure drop is a positive surface indication that the initial cut of the casing has been completed.

Figure 8.4-1: Section Mill.
8.5 Swarf removal and handling.

1 Ideally the majority of the swarf circulated from the well will be removed in a gumbo box arrangement situated close to the bell nipple. However, as this facility will not be available in most cases, the routing through the primary solids control equipment will be crucial, especially the elimination of undesirable swarf traps.

2 All internal restrictions and instrumentation, metering devices, etc. Should be removed from the flow line. Sections with potential for swarf build-up and blockage may need to be temporarily substituted with open trough sections. Suitable access points for rodding the flow line in order to disturb blockages should be provided. Facility to jet the flow line may be useful - temporary connection from header box jetting line?

3 Returns should be directed to feed into the top of the shaker header boxes, i.e. "top-dumped". If practical, the lower regions of the box should be plated off so that swarf "flows" with the mud to the shakers and does not build up in the sump. Do not seal off the sump completely as draining through the dump valve may be necessary at some stage.

4 The arrangement for managing flow to the shakers may need attention. Thule shakers have gates which lift up to open a slot and perforated guide plates, both features tend to trap swarf and cause it to build up. If not cleared then minor collections of swarf can become major accumulations quite quickly. A weir arrangement is recommended in place of the gates and the perforations should be covered with thin steel plate.

5 Swarf will tend to bind in the mesh of coarse shaker screens. the finest mesh sizes robust enough to withstand the duty should be established quickly. It should be practical to use 40 or 60 mesh screens on the top and 80 or 100 mesh on the bottom.

6 If the cuttings disposal chute is relatively straight, has a large bore and a convenient intersection point, it may be a practical means of transporting swarf away from the shakers. However, be cautious: a blocked chute can be difficult to clear. A means of getting the swarf from the chute and into skips, and for the regular changing of skips must be devised. A builder's rubbish chute (plastic sections wired together, say 14" minimum ID) is a good means of getting the collected swarf into skips placed on a lower deck.
7 SAFETY NOTE: Metal swarf is pyrophoric and such can spontaneously catch fire. The metal swarf once held in containers, drums or skips should be kept damp and the rig/platform safety officers made aware of the potential fire risk.

8 As a guide to the number of skips required, allow 5 - 6,000 lbs of in situ casing steel per skip (e.g. 106 - 127 feet of 47 ppf 9 5/8" casing). The bulk volume will vary with the form of swarf cut, a skip may be physically full before the allowable load is reached. Weigh a 3/4 full skip on the crane to test the actual situation. Obviously sufficient skips will be required to complete the job or sustain operations until the next scheduled arrival of a supply vessel. As a minimum, maintain sufficient skips on a board to sustain 4 days milling.

9 Grating filters or traps should be placed over drains in the vicinity of the shakers to prevent swarf entering and blocking the lines. Simple steel baskets with grating/mesh panels should be fabricated for installation in the mud return lines immediately downstream of the shakers and in the pit room to strain the flow for small pieces of steel. Ditch magnets should also be positioned in both locations, in pairs. If the facility is available, then mud pump suction strainers should be used sized for the largest tolerable drop in delivery charge pressure. Strainers and magnets must be checked and cleaned frequently by organising a planned cleaning schedule.

10 Milling of long sections of casing results in large transfers of heat energy into milling fluid - high temperatures can be expected (e.g. 180 deg.F while milling at 5600' TVD Central North Sea). Efficient fume extraction and ventilation in the shaker/header box area is required if tolerable working conditions are to be maintained. Examine the practicality of improving the natural ventilation by installing louvers or temporarily opening up sections of walls.

11 Small rakes with round-ended tines assist in moving swarf off the shaker screens. Shovels and potato digging forks will be required for manual handling of swarf.

12 Cleaning points should be established appropriate locations where swarf can build up and where mud spillage's may occur.

13 The wear bushing profile should present a smooth bore through the wellhead to avoid any tendency for swarf to become trapped and build up

14 Unnecessarily functioning BOPs or circulating through additional equipment and valves should be avoided in order to minimise potential damage by swarf to seals and seal areas.

15 In the interests of subsequent equipment and drilling fluid maintenance, it is important that all remaining pieces of milled swarf be removed from the surface facilities on completion of operations. The mud pumps, lines and valves should be fully inspected. In addition to mud lines and pits, this should include the drip tray, trip tank, areas around and under the shakers and places forming natural traps. BOP ram cavities, kill and choke lines, standpipe and choke manifolds should be flushed.
8.6 Hole cleaning and Milling Fluids.

As described in casing milling.

8.6.1 Mud System Selection of Mud Type

As described in casing milling.

8.6.2 Mud properties.

As described in casing milling.
8.7 Section Milling assembly.

Efficient operation requires the tool to be well centralised.

The taper mill and pilot stabilisers should be the same size as the casing drift diameter.

The section mill body diameter should be the largest available to comfortably run inside the casing so that the knives are short, and strong, as possible.

Limit the number of drill collars to that required to provide the maximum anticipated milling weight.

Jar placement should be determined for operating effect *(keep above top of window at all times)*.

Alternatives may be justified for specific tasks and sets of circumstances.

Note: There is a danger of the connections below the section mill working loose with consequent loss of all or part of the pilot assembly. "Lock-up" type connections should be used if available, otherwise connections should be made up "dry" and use of a thread-locking compound considered.

8.7.1 Recommended general assemblies *(add crossovers as necessary)*:

8.7.1.1 Straight Hole

Taper Mill - Near Bit Stabiliser - Section Mill - 4-6 DC - HWDP.

8.7.1.2 Deviated Hole

Taper Mill - Near Bit Stabiliser - Short DC - String Stabiliser - Section Mill - 4-6 DC - Jars - 1-2 DC - HWDP.
8.8 Operating procedures.

1. The fluid circulation rates through section mills are limited by the size of the fluid courses and by the knife-actuating forces developed.

   If the tool features an interchangeable nozzle/orifice then the size selected should be consistent with a flowrate adequate for hole cleaning purposes.

2. The required diameter of the knife cutting circle is dependant on the casing string to be cut/milled across an open hole section.

   The cut should be positioned 10 - 15 feet below a casing coupling to make best use of the enforced stand-off between the strings.

3. Sets of knives can vary in shape, excessively high point-loading could result; Check that each set, including spares, are similar.

   Hinge pins do sometimes bend in service; therefore it is advisable to ensure that a spare set is on site.

   If more than one style of tungsten/carryer matrix is available, confirm that the most suitable is used, generally the hardest, most resilient category.

4. As with any downhole tools, ensure that all lengths and dimensions have been recorded before the assembly is run.

   Confirm that suitable fishing tools are available.

5. Function test the tool at surface. Pump through the tool at the "cutting out" flowrate with the knife travel restricted to the casing ID (if practical) and then fully opened. Increase circulation to the full milling flowrate.

   Record the pressures at each stage, this is useful information when starting the actual operation.

   Check that the knives have opened fully to an even cutting circle.

6. Pin the knives back into the body with insulating tape, String or slivers of wood.

   If left loose, the knives are prone to hanging up in the wellhead and recesses in the casing string.
7 Drift the whole drill string with proper, near-size rabbits.
   • Loose cement or scale may block the tool or impair its operation.

8 Run the mill to the bottom of the proposed window to ensure that the casing bore is clean.

9 Pull back and take string up, down and rotating drags - without pumps.

10 Attempt to locate casing collar so that the window may be accurately positioned.

   For buttress threaded casing: Use casing tally depths as a guide, start 20 ft above the expected collar depth and open up the knives at a low pump rate. RIH slowly, without rotating observing for loss of string weight as the knives drop into the collar recess. Repeat this to be sure of collar depth.

11. Space out the drill string to provide maximum working length at the start of the cut.
   • On a floater consider de-ballasting to provide an increase in initial cut interval.

12. A marine swivel would be used on floating rigs to make the initial cut.
   • Motion compensators generally respond poorly to the lighter weights applied with section mills.
   • The repeated spudding and surging of cutting blades during rig response is likely to result in the premature failure of the cutting structure.
8.9 Section milling - Cutting and milling operations.

1. Start rotating at 50 - 80 rpm and take note of the free rotating torque.
   - Bring pumps up to "cut out" rate a torque increase should be observed. With drill string running smoothly allow the tool to make an initial cut. This may take 5 - 30 minutes. therefore be patient.
   - Once cut is complete be aware of annular fluids, contaminated mud, etc. "U" tubing into the well.
   - Once cut is apparent increase pump rate to allow full opening of the knife blades so they can sit evenly on top of the casing cut.

2. Optimise parameters to initiate a moderate milling rate of 4 - 5 ft/hr. Continue at this rate until it is established that steel cuttings are being returned via the surface equipment.

3. Vary parameters until optimum rate is achieved.

4. Maintain a steady weight by allowing the drawworks to feed off the block line at a continuous rate if possible.

5. Maintain a trend sheet similar to the following.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Time</th>
<th>ROP</th>
<th>RPM</th>
<th>Torque</th>
<th>WOB</th>
<th>Flowrate</th>
<th>Pressure</th>
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</table>
6. Observe for pump pressure increases as already described in casing milling procedures.

7. As knives become worn out the casing will be skimmed for a while before the tool starts to fall inside. Torque changes and increased ROP at lower weights will indicate tool has basically run its life. Establish top of casing by pulling back and tagging top of window with pumps on (no rotation.)

8. Circulate clean prior to POOH.

9. If subsequent runs are required observe the following points.
   - Open the knives at the top of the window section and lightly ream through the section.
   - Cut a new profile on the casing stump with low weight before progressing ahead and optimising new milling parameters.

10. Once window is complete a clean out assembly with a under reamer may be considered if it is vital to remove all debris from the window or to produce a consistent open hole diameter.