HARMONIC DRIVE DIFFERENTIAL TRANSMISSIONS

A differential transmission most commonly consists of a primary constant speed power input, a secondary control input, and an output. The output is varied in velocity or phase as a function of the control input speed or position.

The basic configuration of harmonic drive gearing permits two independent inputs with a common output, lending itself ideally to differential designs. HDUA DIFFERENTIAL TRANSMISSIONS provide this capability to vary the speed or phasing of the output in a very compact package with a convenient in-line configuration.

THE BASIC ASSEMBLY

The Dynamic Spline (DS) is a rigid ring having internal teeth of same number as the Flexspline. It rotates together with the Flexspline and can serve as either the input or output member. It is identified by chamfered corners at its outside diameter.

The Wave Generator (WG) is a thin raced bearing assembly fitted onto an elliptical plug, and normally is the control input member.

The Flexspline (FS) is a non-rigid ring with external teeth on a slightly smaller pitch diameter than the Circular Spline. It is fitted over and elastically deflected by the Wave Generator.

The Circular Spline (CS) is a rigid ring with internal teeth, engaging the teeth of the Flexspline across the major axis of the Wave Generator.
Harmonic drive differential transmissions are available as a component set comprised of the Wave Generator, Flexspline, and Circular and Dynamic Splines, or as a housed unit. The housed unit is provided with grease lubrication.

**ORDERING INFORMATION**

**HDUA 20-80-2-GP**

- HDUA Series differential drive
- Size
- Nominal ratio
- O: Housed unit
- 2: Component set
- Suffix indicating grease lubrication

**CONFIGURATIONS**

**Input Configuration**

- CS Input with $N_S$ rpm
- DS Output with $N_D$ rpm
- WG Control input with $N_W$ rpm

Output adjustment $\Delta N_D = -\frac{N_W}{R}$ when control input ($N_W$) and CS input ($N_S$) in same direction

$\Delta N_D = +\frac{N_W}{R}$ when $N_W$ and $N_S$ in opposite direction

**Output Configuration**

- CS Output with $N_S$ rpm
- DS Input with $N_D$ rpm
- WG Control input with $N_W$ rpm

Output adjustment $\Delta N_S = +\frac{N_W}{R + 1}$ when control input ($N_W$) and DS input ($N_D$) in same direction

$\Delta N_S = -\frac{N_W}{R + 1}$ when $N_W$ and $N_D$ in opposite direction

$R$ as tabulated in PERFORMANCE RATING TABLE, page 6.
HDUA differential transmission offers many advantages not found in other forms of differentials.

**Compact In-Line Configuration**
Concentric configuration of elements makes the overall differential drive small and simple, compared with conventional drives with multiple parts.

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**High Accuracy**
Extremely low backlash combined with high ratio makes it possible to precision control the output phasing or speed without precision trim input.

**Bi-Directional Control**
Phase or speed adjustment can be accomplished through 360° in either direction.

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**Crosscutter and Overprinter**

1. **Intake control**
   Harmonic drive differentials are used for precision web speed control so that the impression is accurately synchronized by photocells to the page size.

2. **Overprinter**
   Harmonic drive differentials ensure that correct register is automatically held and the impression is correctly presented to the crosscutter.

3. **Transfer and collation**
   Harmonic drive differentials continuously maintain justification and text presentation on the run.

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**Flexo-Rotary Press**

1. **Fine web speed control using harmonic drive differentials and stepless speed controllers:**
   1) Intake control
   2) Offtake control
   3) Offtake reeler
   4) Conditioner roll

2. **Register control**
   Harmonic drive differentials are used as register controls for the print roll (5). They may be set by hand or remotely from the print monitor console.
**Positioning**
Positioning with fast traverse and fine setting.

**Phase Shifting**
Continuous running phase adjustment of rotating parts.

**Register Control**
at 1:1 overall ratio.
### DIMENSIONS

#### Type 0 Housed Unit

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* The axial location surfaces at D width must extend radially inward to at least S for Flex spline containment. The surface hardness in the region where the Flex spline abuts is recommended to be RC29-34.
## PERFORMANCE RATING

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<th>Output Torque at CS or DS at 2000 rpm*</th>
<th>at 1450 rpm*</th>
<th>at 500 rpm*</th>
<th>Max. *Input Speed</th>
<th>Moment of Inertia J (kg m² lb-in²)</th>
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* Speed of Circular Spline, or Dynamic Spline — whichever the input element — relative to the control input speed at Wave Generator.

Ex. Main input speed = 500 rpm

Control speed at Wave Generator = 100 rpm in the same direction as Circular Spline

Relative speed of Circular Spline = 500 - 100 = 400 rpm
Below is an example of a typical application for the HDUA differential drive. Ratio selection, speeds, and required control torque are calculated.

The phasing of a pair of work rolls are adjusted while running, with the following operating condition:

Surface speed $V = 200$ feet/min
Roll circumference $(d \times \pi) U_W = 20$ inches
Working torque $M_W = 530$ lb-in
Input shaft speed $n_1 = 500$ rpm
Work roll speed $n_4 = \frac{V}{U_W} = \frac{2400}{20} = 120$ rpm

\[
\frac{Z_1}{Z_2} \cdot \frac{Z_3}{Z_4} = \frac{Z_0}{Z_5} \cdot \frac{n_4}{n_1}
\]

\[
= \frac{80}{81} \cdot \frac{120}{500}
\]

\[
= \frac{2^4 \cdot 5}{2^3 \cdot 3 \cdot 5}
\]

\[
= \frac{2^3}{3^2}
\]

\[
= \frac{16}{16}
\]

\[
= \frac{30}{36}
\]

$Z_1 = 16$  $Z_2 = 30$  $Z_3 = 16$  $Z_4 = 36$

Gearing Plan
An HDUA 25 with a tabulated ratio of 80/81 is provisionally selected from the rating chart. Using these data we obtain:

Internal ratio $i = \frac{Z_0}{Z_5} = \frac{80}{81}$

Rated torque $M_{\text{nom}}$ (@ 1450 rpm) = 513 lb-in

Main drive efficiency CS----DS $n_1 = 90\%$ approx.

Control efficiency $n_2 = 70\%$ approx.

Ratio Selection
Through drive ratio:

\[
ig = \frac{n_4}{n_1} = \frac{Z_1}{Z_2} \cdot \frac{Z_3}{Z_0} \cdot \frac{Z_2}{Z_4}
\]

Speeds

\[n_1 = 500 \text{ rpm}\]
\[n_2 = n_1 \cdot \frac{Z_1}{Z_2} = 500 \cdot \frac{16}{30} = 267 \text{ rpm}\]
\[n_3 = n_1 \cdot \frac{Z_1 \cdot Z_3}{Z_2 \cdot Z_6} = 500 \cdot \frac{16}{30} \cdot \frac{81}{80} = 270 \text{ rpm}\]
\[n_4 = n_1 \cdot \frac{Z_1 \cdot Z_3}{Z_2 \cdot Z_7 \cdot Z_4} = 500 \cdot \frac{16}{30} \cdot \frac{81}{80} \cdot \frac{16}{36} = 120 \text{ rpm}\]

Control Input (WG) = Rotationally fixed.
Torques

\[ M_{d1} = M_{d4} \cdot \frac{Z_1}{Z_2} \cdot \frac{Z_3}{Z_4} \cdot \frac{1}{n_1} \]
\[
= 530 \cdot \frac{16}{30} \cdot \frac{81}{80} \cdot \frac{1}{0.9} = 141 \text{ lb-in}
\]

\[ M_{d2} = M_{d4} \cdot \frac{Z_1}{Z_4} \cdot \frac{1}{n_1} \]
\[
= 530 \cdot \frac{16}{36} \cdot \frac{1}{0.9} = 265 \text{ lb-in}
\]

\[ M_{d3} = M_{d4} \cdot \frac{Z_3}{Z_4} \]
\[
= 530 \cdot \frac{1}{36} = 236 \text{ lb-in}
\]

\[ M_{d4} \]
\[
= 530 \text{ lb-in}
\]

Control Input

The angular displacement \( \Delta \Theta \) at the work rolls when the control input (WG) is rotated by 360°, is calculated as follows:

\[
| \Delta \Theta | = 360^\circ \cdot \frac{Z_3}{Z_4} \cdot \frac{1}{80}
\]
\[
= 360^\circ \cdot \frac{16}{36} \cdot \frac{1}{80} = 2^\circ
\]

The resultant change of web register caused by one revolution of control input is

\[ 20^\circ \cdot \frac{20^\circ}{360^\circ} = 0.11 \text{ inches} \]

Control Torque

\[ T = \text{Working Torque} \cdot \frac{Z_3}{Z_4} \cdot \frac{1}{R} \cdot \frac{1}{n_1} \]
\[
= 530 \cdot \frac{16}{36} \cdot \frac{1}{80} \cdot \frac{1}{0.7}
\]
\[
= 4.2 \text{ lb-in}
\]

COMPOUND GEAR RATIO

Favorable low number gear pairs for equal primary input and output speed are given in the table below.

| Compound ratio for equal peripheral \( Z_0 \) speed \( \frac{Z_0}{Z_5} \) | 80  | 104 | 120 | 128 | 160 | 194 | 200 | 208 | 258 | 260 |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Expression of internal ratio in prime numbers | \( \frac{2^4 \cdot 5}{3^4} \) | \( \frac{2^7 \cdot 3 \cdot 5}{7 \cdot 3 \cdot 5} \) | \( \frac{2^6 \cdot 5}{3^5 \cdot 7} \) | \( \frac{2^6 \cdot 5}{3^6 \cdot 7} \) | \( \frac{2^7 \cdot 3 \cdot 5}{3^7 \cdot 7} \) | \( \frac{2^8 \cdot 5}{3^8 \cdot 7} \) | \( \frac{2^9 \cdot 5 \cdot 13}{3^9 \cdot 7} \) | \( \frac{2^9 \cdot 5 \cdot 13}{3^{10} \cdot 7} \) |
| \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) |
| \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) |
| \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) | \( Z_1 \cdot Z_3 \) | \( Z_2 \cdot Z_4 \) |

Example: \( i = \frac{n_1}{n_4} = \frac{Z_2}{Z_1} \cdot \frac{Z_6}{Z_3} \cdot \frac{1}{n_1} \)

\[ i = \frac{27}{26} \cdot \frac{80}{81} \cdot \frac{39}{1} = 1 \]
LUBRICATION

As with other harmonic drive transmissions oil lubrication is preferred. Although HDUA sets may be used in any attitude, it is essential that the Wave Generator bearing and gear teeth be properly lubricated. Minimum required oil amounts are tabulated below, but the actual amount will depend on the size of the housing.

In the case of a horizontal shaft installation, the appropriate oil level below the gear set center line must be maintained as tabulated. For vertical mounting, the recommended level is the center line of the upper Wave Generator bearing balls.

Oil Level and Minimum Oil Quantity

<table>
<thead>
<tr>
<th>HDUA</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>50</th>
<th>65</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>A mm</td>
<td>12</td>
<td>15</td>
<td>31</td>
<td>38</td>
<td>44</td>
<td>62</td>
<td>75</td>
<td>94</td>
</tr>
<tr>
<td>Qty</td>
<td>1.4</td>
<td>2.8</td>
<td>7</td>
<td>10</td>
<td>20</td>
<td>50</td>
<td>75</td>
<td>140</td>
</tr>
</tbody>
</table>

Oil Temperature

In normal use, the oil temperature must not exceed 90°C, as oil loses its lubricating capability quickly above this limit.

Oil Change

The first change should be performed after 100 hours of operation. The need to perform subsequent oil changes will depend on operating conditions, but should take place at intervals of approximately 1,000 running hours.

Grease Lubrication

HDUA differential drives may be operated with grease lubrication at rated torque but at a reduced duty cycle. Imperial Molub Alloy No.2 is recommended.

Grease lubrication may be used in applications where the duty cycle is less than 10 percent time-on and the length of time-on does not exceed 10 minutes of continuous operation. The maximum input speeds allowable for units lubricated by Molub Alloy No.2 are as follows:

<table>
<thead>
<tr>
<th>HDUA</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>50</th>
<th>65</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. rpm</td>
<td>2,800</td>
<td>2,200</td>
<td>1,700</td>
<td>1,400</td>
<td>1,000</td>
<td>850</td>
<td>700</td>
<td>550</td>
</tr>
</tbody>
</table>

Harmonic Grease HC-1

As a result of an extensive search for a grease that will render improved performance in harmonic drive component sets, a new grease, named Harmonic Grease HC-1, has been developed. With Harmonic Grease HC-1, UNITS MAY BE OPERATED CONTINUOUSLY.

An important consideration in grease lubrication is ensuring that as much grease as possible is retained where lubrication is needed. To achieve this, it is recommended that the axial location surfaces at D width extend radially inward to the dimension shown. However, such extension is not recommended for oil lubrication.

Grease Changes

When operating the HDUA at rated torque, change grease after about 1,000 running hours. Light duty operation may permit longer service intervals. To change grease, completely disassemble and clean units before re-greasing. Apply grease generously inside the Flex spline, the Wave Generator bearing, and the teeth of both the Circular and Dynamic Splines and the Flex spline.

The approximate amount of grease needed for each harmonic drive HDUA component set is tabulated below:

<table>
<thead>
<tr>
<th>HDUA</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>50</th>
<th>65</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr. Weight</td>
<td>18</td>
<td>30</td>
<td>60</td>
<td>100</td>
<td>150</td>
<td>320</td>
<td>570</td>
<td>1150</td>
</tr>
</tbody>
</table>

Grease Packed HDUA Housed Unit (HDUA-O-GP)

HDUA Type O housed unit may be supplied with HC-1 grease packed at the factory. Specify GP.
Efficiency varies depending on input speed, ratio, load level, temperature, and type of lubrication. The effects of these factors are illustrated in the curves shown.

**Efficiency vs. Speed, Temperature, Reduction Ratio, and Lubrication**

**Chart 1**
Input Speed: 500 RPM  
Lubricant: Gear Oil No. 2

**Chart 4**
Input Speed: 500 RPM  
Lubricant: Harmonic Grease SK-1

**Chart 2**
Input Speed: 1,000 RPM  
Lubricant: Gear Oil No. 2

**Chart 5**
Input Speed: 1,000 RPM  
Lubricant: Harmonic Grease SK-1

**Chart 3**
Input Speed: 2,000 RPM  
Lubricant: Gear Oil No. 2

**Chart 6**
Input Speed: 2,000 RPM  
Lubricant: Harmonic Grease SK-1