Foreword

The formulation of this National Standard was initiated by the Agricultural Machinery Testing and Evaluation Center (AMTEC) under the project entitled "Enhancing the Implementation of the AFMA Through Improved Agricultural Engineering Standards" which was funded by the Bureau of Agricultural Research (BAR) of the Department of Agriculture (DA).

This standard has been technically prepared in accordance with PNS 01-4:1998 (ISO/IEC Directives Part 3:1997) – Rules for the Structure and Drafting of International Standards. It provides specifications and proper application of drives using straight bevel gears.

The word "shall" is used to indicate requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted.

The word "should" is used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that certain course of action is preferred but not necessarily required.

In the preparation of this standard, the following references were considered:

Browning power transmission equipment. 1975. Catalog number 8.

Baumeister, Theodore (ed.) 1997. Mark's handbook for mechanical engineers. 10th Edition. Mc Graw Hill Book Company, USA.

Faires, V. M. 1969. Design of Machine Elements. Macmillan Company, New York USA.

Horton, H. L. (Ed.) 1984. Machinery's handbook. 23rd Edition. Industrial Press Inc, New York.

Quayle, J. P. (Ed.) 1971. Kempe's engineer's yearbook. Volume 1. Morgan-Grampian Book Publishing Co. Ltd, London.

Shigley, Joseph, E. 1977. Mechanical engineering design. 3rd Edition. Mc Graw Hill Book Company, USA.

Engineering Materials – Straight Bevel Gears for Agricultural Machines – Specifications and Applications

1 Scope

This standard establishes specifications and provides sufficient technical information for the proper application of straight 90° bevel gears for agricultural machinery.

2 Reference

The following normative reference contains provisions which, through reference in this text, constitute provisions of this standard:

PAES 305:2000, Engineering Materials – Keys and Keyways for Agricultural Machines – Specifications and Applications

3 Application

Bevel gears may be used to transmit power between shafts at practically any angle. For the purpose of this standard, only straight bevel gears with a shaft angle of 90° will be discussed.

4 Definitions

4.1
bevel gears
gears which are used to transmit motion and power to shafts having intersecting axes

4.2
straight bevel gears
bevel gears whose teeth are straight but the sides are tapered so that they would intersect the axis at a common point called the pitch cone apex if extended inward

4.3
miter gears
bevel gears having equal numbers of driver and driven gear teeth and operate at axes with right angles

4.4
module
the quotient of the pitch, expressed in millimeters, to the number π (or the quotient of the reference diameter, expressed in millimeters, to the number of teeth)

4.5
circular pitch
the length of the arc of the pitch circle between two consecutive corresponding profiles which is measured at the large end of the tooth

4.6
pitch diameter
the diameter of the pitch circle at the large end of the tooth

4.7
addendum angle
the angle between the elements of the face cone and the pitch cone (see Fig. 1)

4 .8
dedendum angle
the angle between the elements of the root cone and the pitch cone (Fig. 1)

4.9
facewidth
the length of teeth along the cone distance (Fig. 1)

4.10
cone distance
the distance from the end of the tooth to the pitch apex (Fig. 1)

4.11
pitch angle
the angle formed between an element of the pitch cone and the bevel gear axis, it is the half angle of the pitch cone (Fig. 1)

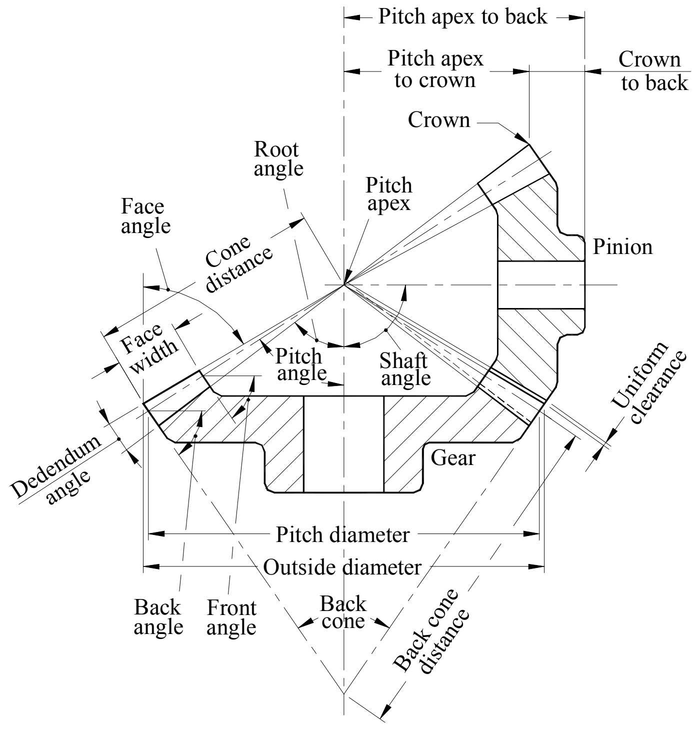

Figure 1 – Nomenclature of bevel gears

4.12
back angle
the angle between an element of the back cone and the plane of rotation (Fig. 1)

4.13
back cone
the angle of a cone whose elements are tangent to a sphere containing a trace of the pitch circle (Fig. 1)

4.14
back cone distance
the distance along an element of the back cone from the apex to the pitch circle (Fig. 1)

4.15
mounting distance
for assembled bevel gears, the distance from the crossing point of the axes to the registering surface, measured along the gear axis; ideally it should be identical to the apex to back

4.16
mounting surface
the diameter and/or plane of rotation surface which is used in locating the gear in the application assembly

4.17
crown
the sharp corner forming the outside diameter (Fig. 1)

4.18
crown-to-back
the distance from the crown to the rear of the gear (Fig. 1)

4.19
pitch apex to back
the distance along the axis from apex of pitch cone to a locating registering surface on back (Fig. 1)

4.20
root angle
the angle formed between a tooth element and the axis of the bevel gear (Fig. 1)

4.21
shaft angle
the angle between meshing bevel gear axes: also, the sum of the two pitch angles (Fig. 1)

NOTE For the purpose of this standard, the shaft angle shall be 90°.

4.22
face angle
the between an element of the face cone and its axis (Fig. 1)

4.23
front angle
the angle between an element of the front cone and a plane of rotation (Fig. 1)

4.24
heel
the portion of the bevel gear tooth near the outer end

4.25
toe
the portion of the bevel gear tooth near the inner end

5 Materials

Straight bevel gear materials discussed in this standard are AISI designation C1045 and 4140 (as hot-rolled), its mechanical properties are in accordance with Table 1.

Table 1 – Mechanical Properties of helical gear materials

AISI No.	Ultimate tensile strength, MPa	Brinell hardness number
1045	586-724	175-215
4140	621-689	185-210

6 Recommended design practices

6.1 Calculation of gear dimensions

Table 2 specifies the formula for calculating the different dimensions of standard straight bevel gears.

Table 2 – Bevel gear calculations

Dimension	Driver	Driven
Working depth	$h_k = \frac{2.000}{P_d}$	Same as driver gear
Whole depth	$h_t = \frac{2.188}{P_d}$	Same as driver gear
Pitch diameter	$d = \frac{t_1}{P_d}$	$D = \frac{t_2}{P_d}$
Pitch angle	$\gamma = tan^{-1} \frac{t_1}{t_2}$	$\Gamma = 90° - \gamma$
Outer cone distance	$A_o = \frac{D}{2 \sin \Gamma}$	Same as driver gear
Circular pitch	$p = \frac{\pi}{P_d}$	Same as driver gear

Table 2 – Continued

Dimension	Driver	Driven
Addendum	$a_1 = h_k - a_2$	$a_2 = \frac{0.540}{P} + \frac{0.460}{P(t_2/t_1)^2}$
Dedendum	$b_1 = \frac{2.188}{P_d} + a_1$	$b_2 = \frac{2.188}{P_d} + a_2$
Clearance	$c = h_t - h_k$	Same as driver gear
Dedendum angle	$\delta_1 = tan^{-1}\frac{b_1}{A_o}$	$\delta_2 = tan^{-1}\frac{b_2}{A_o}$
Face angle of blank	$\gamma_O = \gamma + \delta_2$	$\Gamma_O = \Gamma + \delta_1$
Root angle	$\gamma_R = \gamma - \delta_1$	$\Gamma_R = \Gamma - \delta_2$
Outside diameter	$d_O = d + 2a_1 \cos\gamma$	$D_O = D + 2a_2 \cos\Gamma$

6.2 Power ratings

6.2.1 Power ratings presented in this standard are based on modules, and pressure angle that are shown in Table 3. The material used as the basis of the power ratings is of AISI steel designation C1045.

Table 3 - Standard modules

Module, mm/tooth	1.25	1.5	2.0	2.50	3.0	4.0	5.0	6.0	8.0
Pressure angle, °	20	20	20	20	20	20	20	20	20

6.2.2 Power ratings of straight bevel and miter gears are shown in Tables 4 and 5, respectively.

6.3 Bearing spacing

For both straddle mounted and overhung mounted gears the space between bearings should never be less than 70% of the pitch diameter of the gear. On over hung mounted gears the spread should be at least 2 ½ times the overhang and, in addition the shaft diameter should be equal to or preferably greater than the overhang to provide sufficient shaft stiffness.

Table 4 –Power ratings* of straight bevel gears, watts

Module	Gear ratio	Gear combination (No. of teeth)		rpm of smaller gear																	
				40	**60**	**80**	**100**	**200**	**400**	**600**	**800**	**1,000**	**1,200**	**1,400**	**1,600**	**1,800**	**2,000**	**2,200**	**2,400**	**2,600**	**2,800**
1.25	2.00	20	10	20	28	34	41	66	106	137	164	187	209	229	257	266	282	299	314	329	343
1.50	1.50	24	16	42	57	71	84	136	214	277	330	378	421	462	518	534	568	600	630	660	688
1.50	2.00	24	12	48	65	81	95	152	239	307	366	418	465	509	570	588	624	659	692	724	754
1.50	2.00	32	16	83	112	138	161	256	397	508	602	686	763	833	932	961	1,019	1,075	1,128	1,179	1,229
1.50	3.00	48	16	216	285	346	400	620	939	1,188	1,400	1,587	1,756	1,912	2,135	2,194	2,324	2,447	2,565	2,678	2,786
1.50	4.00	64	16	420	548	658	757	1,152	1,722	2,164	2,538	2,868	3,167	3,442	3,837	3,939	4,168	4,385	4,592	4,791	4,982
2.00	1.50	27	18	118	159	195	228	365	568	728	864	986	1,096	1,198	1,341	1,382	1,467	1,547	1,625	1,699	1,770
2.00	2.00	36	18	227	303	369	429	672	1,030	1,309	1,547	1,757	1,948	2,124	2,374	2,443	2,589	2,728	2,861	2,989	3,112
2.00	2.00	36	18	227	303	369	429	672	1,030	1,309	1,547	1,757	1,948	2,124	2,374	2,443	2,589	2,728	2,861	2,989	3,112
2.00	2.00	48	24	382	505	613	710	1,101	1,672	2,117	2,495	2,829	3,132	3,411	3,809	3,916	4,147	4,368	4,578	4,780	4,975
2.00	3.00	54	18	573	750	903	1,041	1,591	2,386	3,004	3,526	3,988	4,407	4,792	5,344	5,488	5,807	6,111	6,401	6,680	6,948
2.00	4.00	72	18	1,101	1,425	1,703	1,951	2,937	4,351	5,444	6,369	7,184	7,923	8,602	9,581	9,830	10,392	10,927	11,439	11,930	12,402
2.50	1.50	30	20	266	356	435	506	799	1,230	1,568	1,856	2,111	2,343	2,556	2,859	2,943	3,120	3,289	3,451	3,606	3,755
2.50	2.00	40	20	505	667	809	936	1,450	2,200	2,783	3,279	3,717	4,115	4,481	5,002	5,142	5,446	5,735	6,011	6,276	6,531
2.50	2.00	50	25	748	984	1,189	1,372	2,111	3,182	4,015	4,721	5,345	5,911	6,432	7,176	7,373	7,805	8,216	8,608	8,985	9,348
2.50	3.00	60	20	1,243	1,617	1,938	2,224	3,368	5,014	6,288	7,366	8,317	9,179	9,972	11,112	11,404	12,061	12,686	13,283	13,856	14,407
2.50	4.00	60	15	1,460	1,888	2,255	2,582	3,882	5,748	7,189	8,408	9,483	10,456	11,352	12,643	12,970	13,711	14,417	15,091	15,738	16,360
3.00	2.00	40	20	825	1,086	1,312	1,516	2,335	3,524	4,448	5,232	5,925	6,553	7,131	7,958	8,177	8,656	9,112	9,549	9,967	10,370
3.00	3.00	48	16	1,383	1,800	2,158	2,478	3,757	5,599	7,024	8,230	9,295	10,259	11,146	12,421	12,749	13,484	14,184	14,852	15,493	16,110
3.00	4.00	64	16	2,632	3,388	4,034	4,608	6,888	10,150	12,667	14,794	16,670	18,368	19,930	22,187	22,751	24,044	25,274	26,450	27,578	28,663
3.00	4.00	72	18	3,207	4,118	4,896	5,588	8,330	12,250	15,272	17,826	20,078	22,116	23,991	26,703	27,378	28,930	30,406	31,817	33,170	34,472
4.00	2.00	36	18	1,477	1,936	2,334	2,690	4,119	6,188	7,794	9,154	10,356	11,445	12,448	13,884	14,260	15,091	15,882	16,638	17,363	18,061
4.00	2.00	42	21	1,944	2,540	3,054	3,514	5,357	8,018	10,080	11,826	13,369	14,765	16,051	17,896	18,375	19,441	20,455	21,424	22,353	23,248
4.00	2.00	48	24	2,451	3,193	3,833	4,404	6,688	9,979	12,527	14,684	16,589	18,313	19,900	22,180	22,768	24,083	25,334	26,530	27,677	28,781
4.00	3.00	45	15	2,656	3,439	4,112	4,712	7,101	10,531	13,182	15,423	17,402	19,193	20,841	23,215	23,818	25,183	26,481	27,722	28,912	30,058
4.00	4.00	60	15	5,031	6,448	7,658	8,732	12,988	19,065	23,750	27,706	31,196	34,353	37,258	41,461	42,504	44,907	47,194	49,379	51,476	53,493
5.00	2.00	30	15	1,933	2,532	3,050	3,514	5,375	8,067	10,155	11,924	13,487	14,903	16,207	18,074	18,562	19,643	20,671	21,653	22,596	23,503
5.00	3.00	45	15	4,789	6,175	7,362	8,418	12,616	18,627	23,268	27,190	30,651	33,783	36,664	40,823	41,869	44,255	46,524	48,693	50,774	52,776
5.00	4.00	60	15	9,020	11,516	13,644	15,529	22,992	33,631	41,825	48,744	54,845	60,364	65,441	72,799	74,608	78,809	82,805	86,624	90,287	93,812
6.00	2.00	32	16	3,532	4,602	5,524	6,347	9,638	14,380	18,052	21,160	23,905	26,390	28,677	31,963	32,810	34,705	36,508	38,231	39,884	41,475
6.00	3.00	42	14	6,881	8,854	10,541	12,041	17,996	26,517	33,090	38,645	43,545	47,979	52,058	57,952	59,427	62,804	66,016	69,086	72,031	74,865
6.00	4.00	56	14	12,952	16,507	19,533	22,214	32,817	47,921	59,550	69,367	78,024	85,854	93,057	103,504	106,063	112,022	117,691	123,108	128,305	133,305
8.00	2.00	30	15	6,762	8,768	10,492	12,028	18,154	26,956	33,761	39,517	44,598	49,196	53,429	59,522	61,075	64,580	67,914	71,101	74,159	77,101

* Based on 20° pressure angle and AISI steel designation C1045.

Table 5 – Power ratings* of straight miter gears, watts

Module	Number of teeth	Gear rpm																	
		40	60	80	100	200	400	600	800	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800
1.25	16	10	14	17	21	35	56	74	90	103	116	128	144	149	159	169	254	186	195
1.50	15	14	20	25	30	50	82	107	129	149	167	183	206	214	228	241	362	266	278
1.50	18	21	29	37	43	72	116	151	182	209	234	258	290	300	319	338	508	372	389
1.50	21	29	40	50	59	97	156	203	243	280	313	343	386	399	424	449	674	494	516
1.50	30	61	83	103	121	196	310	401	479	548	611	669	751	775	824	870	1,306	957	998
1.50	20	26	36	45	53	88	142	185	222	255	286	314	352	364	388	410	616	452	472
1.50	25	42	57	71	84	137	219	283	339	389	434	476	535	552	587	621	932	683	713
2.00	24	85	116	144	169	274	432	558	666	762	849	929	1,042	1,076	1,143	1,207	1,811	1,327	1,384
2.00	25	93	126	156	184	297	468	603	719	822	916	1,003	1,125	1,160	1,233	1,301	1,953	1,431	1,492
2.00	28	117	159	196	230	370	581	748	890	1,017	1,132	1,239	1,388	1,431	1,520	1,605	2,407	1,763	1,838
2.00	32	130	176	216	253	406	633	813	966	1,102	1,226	1,340	1,501	1,548	1,643	1,733	2,599	1,903	1,984

* Based on 20° pressure angle and AISI steel designation C1045.

6.4 Service factors

Selection of gears is based on type of load and the method of lubrication. Service factors for type of load and type of lubrication are given in Tables 6 and 7 respectively. The service is computed as follows:

Service factor = service factor for load + service factor for lubrication...……....[Eq. 1]

Table 6 – Service factors for type of load

Hours of operation per day	Uniform loading	Light shock	Heavy shock
8-10	1.0	1.2	1.4
11-16	1.1	1.3	1.5
17-24	1.2	1.4	1.6

Table 7 – Service factors for type of lubrication

Type of lubrication	Service factor
Intermittent	0.7
Grease	0.4
Oil, drip	0.2
Oil, bath	-

6.5 Minimum number of teeth

The minimum number of teeth to mesh with another gear is shown on Figure 2.

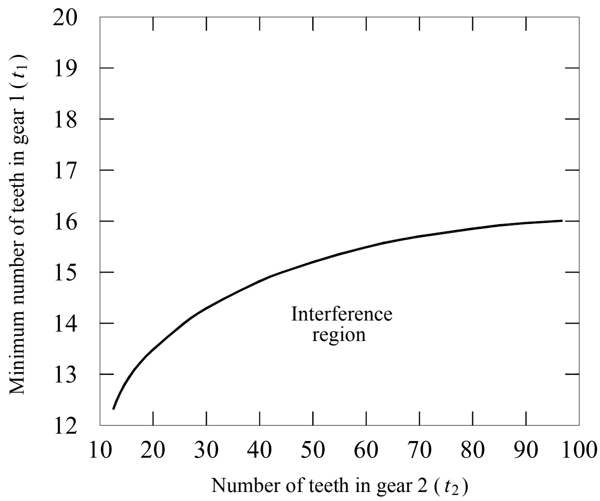

Fig. 2 – Minimum number of teeth for 20° full-depth

6.6 Gear ratio

6.6.1 Gear ratio is the ratio between the number of teeth of the driven and the driver gear (see Equation 2).

$$Gear\ ratio = \frac{t_2}{t_1} \quad \text{……………………………………………………………..[Eq.2]}$$

Where: t_2 = number of teeth of the driven gear
t_1 = number of teeth of the driving gear

6.6.2 Hunting tooth gear ratio

6.6.2.1 When using a hunting tooth gear ratio, a particular tooth in the driver gear must mesh once with every tooth on the meshing gear when the driver gear has completed as many revolutions as the number of teeth in the meshing gear. This is done in order to distribute the wear more evenly.

6.6.2.2 In a hunting tooth gear ratio, the teeth in a pair of meshing gears are such that they do not have a common divisor. Hunting tooth gear ratios are obtained by having the sum of the teeth in each pair equal to a prime number.

6.7 Design power

6.7.1 The required power is computed as follows:

$$Design\ power = \frac{Power\ to\ be\ transmitted\ x\ service\ factor}{Load\ distribution\ factor} \quad \text{……………………..[Eq. 1]}$$

6.7.2 Load distribution factors are presented in Table 8.

Table 8 – Load distribution factors for bevel gears

Type of mounting	Load distribution factor
Both gears straddle mounted	1 to 1.1
On gear straddle, one over hung	1.1 to 1.25
Both gears overhung	1.25 to 1.4

7 Markings

7.1 The following information shall be marked on the gear:

a) Module

b) Number of teeth

c) Pitch angle

d) Manufacturer's name and/or its trademark

7.2 The following information shall be marked on the packaging:

a) Module

b) Number of teeth

c) Pitch angle

d) Manufacturer's name, trademark, and address

8 Safety

8.1 Enclosing the drive with covers is recommended for safety and to avoid foreign materials from getting in contact with the drive.

8.2 Make drive inspection on a periodic basis. Inspect gears for wear and tear, for quality of lubricant, and for its alignment. Tightness of keys and setscrews should also be inspected periodically.

8.3 Use gears with proper markings.

8.4 Use proper keys as specified in PAES 304:2000, Keys and Keyways for Agricultural Machines.

Annex A
(informative)

Example of bevel gear drive selection

A.1 Given parameters

A drive is desired to transmit a power of 1200 W from a 200 rpm driver shaft to a 100 rpm driven shaft with a power source operating for 12 h/day at heavy shock load and with oil (bath) lubrication. Mounting of bearings is such that both gears are overhung.

A.2 Speed ratio

The speed ratio is computed as:

$$Speed\ ratio = \frac{n_1}{n_2}$$

where:
n_1 = rpm of driver gear
n_2 = rpm of driven gear

$$Speed\ ratio = \frac{n_1}{n_2} = \frac{200}{100} = 2.0$$

A.3 Service factor

From Tables 6 and 7, the service factor for load and lubrication are 1.5 and 0.0 respectively. Thus, the service factor is computed as:

$$Service\ factor = 1.5 + 0 = 1.5$$

A.4 Load distribution factor (LDF)

Load distribution factor when both gears are overhung ranges from 1.25 – 1.40 (Table 8). Use an average LDF value of 1.325 for the computation of the design power on the assumption that the material where the gear shall be mounted is average on strength.

A.5 Design power

The design power is computed as:

$$Design\ power = \frac{Power\ to\ be\ transmitted\ x\ service\ factor}{Load\ distribution\ factor}$$
$$= \frac{1{,}200 \times 1.5}{1.325}$$
$$= 1{,}358\,W$$

A.6 Module and number of teeth

Given the design power and rpm of the driver shaft, and referring to Table 4, the following can be obtained:

Module = 2.5
Number of teeth:
  Driven = 40 teeth
  Driver = 20 teeth

A.7 Pitch angle

A.7.1 Driver gear

The pitch angle of the driver gear is computed as:

$$\begin{aligned}\gamma &= tan^{-1}\frac{t_1}{t_2}\\ &= tan^{-1}\frac{20}{40}\\ &= 26.56°\end{aligned}$$

A.7.2 Driven gear

The pitch as angle of the driven gear is computed as:

$$\begin{aligned}\Gamma &= 90° - \gamma\\ &= 90° - 26.56\\ &= 63.44°\end{aligned}$$