Control tests of main safety requirements of a flail mower, according to EN standards

Fanigliulo R., Fornaciari L., Pochi D., Vassalini G.
CRA – ING, Agriculture Research Council - Agricultural Engineering Research Unit
Via della Pascolare 16, 00016 Monterotondo (Rome), Italy
Tel.: +39 0690675233; Fax: +39 0690625591
E-mail: roberto.fanigliulo@entecra.it

Abstract
The manufacturers of agricultural machines must accurately evaluate the risks associated to their utilization and equip them with safety devices. By applying the norms and technical specifications of the Directive 98/37/EC it is possible to obtain the presumption of CE conformity that allows the free trading of said products. The standardization bodies (ISO, EN) issued a series of norms fixing the minimum safety requirements and the relative control tests for the main categories of agricultural machinery.
This paper reports the results of tests on a flail-mower aimed at verifying the sound pressure and sound power levels, the parking stability and the guards effectiveness against accidental ejection of materials according to the reference standards.
The flail-mower was driven by a 58,8 kW tractor that represented an external source of noise. The measurements of A-weighted sound pressure levels (L_{pA}) and of C-weighted sound peak levels ($L_{pC,peak}$), showed values higher than 85 dB(A). Consequently, the sound power levels have been measured in a fictitious hemispheric zone, comprising the tested machine, showing a maximum value of 104,6 dB(A).
The guards against the accidental ejection of materials have been tested into an "eject-chamber" delimited by Kraft paper target-panels. The number of outward perforations determined by the impacts of test materials, used as projectile on the target-panels, indicated the guards suitability. The results showed that the guards resulted in compliance with the standard.
Finally, the flail-mower has been placed on a 13° inclined plane, showing to be stable in parking, independently from its orientation.

Keywords: agricultural machinery, sound pressure, sound power, stone ejection, parking stability.

Introduction
The manufacturers of agricultural machines, during the development of their products, must accurately evaluate the risks associated to their utilization and equip them with safety devices. By applying the norms and technical specifications of the Directive 98/37/EC it is possible to obtain the presumption of CE conformity that allows the free trading of said products. The standardization bodies (ISO, EN) issued a series of norms fixing the minimum safety requirements and the relative control tests for the main categories of agricultural machinery.

At CRA-ING it has been constituted the CPMA (Agricultural Machinery Testing Centre), a work-group fitted up with specific equipments, test areas and updated instrumentations aimed at verifying the compliance of the machines with the standards in force and at studying proper solutions for improving the safety conditions and solving eventual non-conformity problems. As example of CPMA test activity, this paper reports the results of tests on a flail-mower (from the normal production line), aimed at verifying: the

levels of sound pressure and sound power; the parking stability (according to EN ISO 4254-1:2005); the effectiveness of the guards against the accidental ejection of materials (according to EN 745:1999).

Materials and methods

Characteristics of the machine

The tested flail mower is an operating machine mounted on the tractor's three point linkage and driven by the tractor's power take off (fig. 1). It is used in the shredding of shrubby and/or grassy soil covering, straw and pruning residues with diameter up to 30 mm. The steel mainframe has been designed for resisting to the severe shocks and vibrations typical of this kind of machine; a second bowed frame has the function of connecting the machine to the three point linkage and can move sideways, when, for instance, a trunk is met along the row. The movement from the p.t.o. to the tool holder rotor is transmitted by means of a system consisting of a drive shaft (transversal referring to the advancing direction) that ends in a drive pulley; this is connected, by means of 4 V-belts, to the driven pulley at the tip of the tool holder rotor, where the tools are radially bolted. These are represented by "double L" blades with a sharpened edge. The tested flail mower had a working width of 1.40 m and a total mass of 620 kg.

Figure 1. The tested flail mower

Sound pressure levels tests

As to the sound pressure, according to the EN ISO 4254-1:2005 standard, the basic parameters to measure were: the level of the A-weighted sound pressure, L_{pA}, and the level of the C-weighted peak, $L_{pC,peak}$. The reference standard specifies the point in which the instruments must be placed; the measurements must be done on a reflecting surface, under free sound field conditions.

The sound pressure levels have been measured for frequency bands in $^1/_3$-octaves in the range 12.5 Hz to 20 kHz, by means of a B&K instrumental chain that consisted of a real-time frequency analyzer (mod. 2260), a microphone (mod. 4810), a sound level calibrator (mod. 4231) and a reference sound source (mod. 4204) (fig. 2). Such instruments are in compliance with the standards (respectively: IEC 651/1979, IEC 804/1985, IEC 1260/1995, IEC 942/1988 class 1) and underwent calibration in a SIT centre (Italian Calibration Service). Before and after the tests, the deviations from the initial calibration value have been verified by means of the calibrator.

The source of power used in the tests was represented by a 58.8 kW tractor. The power-take-off speed has been measured by means of an optical revolution counter (accuracy: 1%). The tractor-flail mower connection has been realized through interposing a special single-axle trolley equipped with a three point linkage and an extended drive-shaft transmission, with the aim of increasing the distance between the tested machine and the external source of noise (the tractor). After a preliminary heating phase, the measurements have been made under optimum temperature conditions of the organs of both tractor and operating machine.

Figure 2. The real-time frequency analyzer, the microphone and the sound level calibrator (left); the reference sound source (right)

For the machines driven by tractor's PTO, the background noise (K_{1A}) is measured in the micro-phonic place predisposed for the test, while the tractor works with PTO disconnected, at an engine speed corresponding to the speed chosen for normal operating machine working. The background noise (also including the wind noise), expressed as weighted sound pressure level, resulted at least 6 dB(A) lower than the level required by the standard for the tested flail mower.

The following formula has been used in order to obtain the A-weighted sound pressure level of background noise:

$$K_{1A} = -10 \log10 (1-10^{-0,1\,\Delta L}) \quad [dB(A)]$$

where ΔL is the difference between the different sound pressure levels measured in a specific position of the external power source (the tractor), respectively working and not working. The formula is valid in the interval $6 < \Delta L < 15$ dB(A); for $\Delta L > 15$ dB(A) K_{1A} is equal to 0 and for $\Delta L < 6$ dB(A) the measurement is considered invalid.

The environmental correction (K_{2A}) has been determined using a sample sound source having the characteristics required by the ISO 6926:1999 standard, that was positioned in the same place of the tested machine. According to the EN ISO 3744:1995 standard, the sound power levels of the sample source have been calculated with the following formula:

$$K_{2A} = L^{*}_{w} - L_{wr}$$

where:
L^{*}_{w} = sound power level determined by the reference sound source, without environmental correction;
L_{wr} = certified sound power level for the reference source.

According to these considerations, the following tests have been conducted:

- Measurement of the environmental background noise;
- Determination of the sound pressure level produced by the reference sound source (working at a speed of 2282 min^{-1});
- Determination of the background noise produced by the external power source, represented by the tractor and the trolley, working at a P.T.O. speed of 540 min^{-1} without load;
- Determination of the sound pressure produced by the system tractor-trolley-operating machine working at a P.T.O. speed of 540 min^{-1} without load.

The measurements of the sound pressure have been made without driver. The position of the microphone has been determined depending on characteristics of the three point linkage of the tractor as required by standard (appendix B, point B.2 6a) for the machines driven by an external source of power.

The data acquisition started immediately after having observed a deviation lower than 2 dB(A) in three, consecutive measurements: five replications have been made with a sampling time of 60 s. The sound pressure level has been calculated by means of the formula:

$$L_{pA} = L'_{pA} - K_{1A} - K_{2A} \quad [dB(A)]$$

(the presence of the apex indicates measured values; the remaining are the emission values).

The adopted uncertainty for the A-weighted sound pressure has been that defined in the EN ISO 12001:1997 standard (reproducibility standard deviation), resulting equal to 2.5 dB(A).

Sound power level tests

The EN ISO 4254-1:2005 standard allows to estimate the level of sound pressure generated by a sound source on a test surface under free sound-field conditions, from measurements made in proximity of one or more reflecting planes, so that it is possible to calculate the corresponding sound power. In this case the parameters that must be measured are the sound pressure mean level (L'_p) with tested sound source working and the background sound pressure mean level (L''_p), both referred to the same test surface. From them it is possible to calculate the superficial sound pressure level by applying the correction factors, K_{1A} and K_{2A}, respectively for the effects of the background noise and of the reflected sound. The level of the sound power, L_w, is finally determined by means of the formula:

$$L_w = L_{pf} + 10 \lg \frac{S}{S_0} \quad [dB(A)]$$

The standard requires 10 micro-phonic positions dislocated on an hemispheric surface, $S = 2 \Pi r^2$, that includes the sound source and is delimited by the reflecting plane. The test surface and the 10 points are schematically shown in fig. 3 and their coordinates are reported in the table 1.

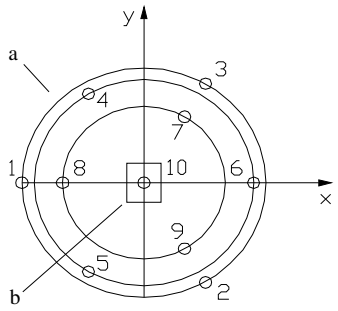

Figure 3. Top view of the hemispheric surface (a) surrounding the sound source (b) and of the 10 micro-phonic positions

Table 1. Coordinates of the 10 micro-phonic positions

Micro-phonic position	X (m)	Y (m)	Z (m)
1	- 3,96	0	0,60
2	2,00	- 3,44	0,60
3	2,00	3,44	0,60
4	- 1,80	3,08	1,80
5	- 1,80	- 3,08	1,80
6	3,56	0	1,80
7	- 1,32	2,28	3,00
8	- 2,64	0	3,00
9	1,32	- 2,28	3,00
10	0	0	4,00

Parking stability

The EN ISO 4254-1:2005 reports the test procedure aimed at verifying the parking stability of the operating machines on hard surfaces having an inclination angle up to 8.5°, in all directions. Such a test has been performed on a plane with an inclination of 13° ± 0,5° (fig. 4) higher than 8,5° required by the standard.

Figure 4. The machine on a tilted plan

Accidental ejection of materials

The wide diffusion of flail mowers determined, from the point of view of safety, an increase of the risk of accidents determined by the ejection of materials as stones, pebbles and/or fragments of tool crashed for the impact with rocks. Such an issue is the subject of the EN 745:1999 standard that reports the minimum safety and control requirements for both the phases of project design and realization of machines, together with the criteria to be followed in the tests aimed at verifying said requirements.

The tested flail mower was equipped with a couple of self-steering rear wheels used for adjusting the cutting height. The protections are represented by two rubber strip covers (fig. 1). The upper cover is fixed on the frame of the cutting chamber, as the lower cover is bolted to the beam supporting the wheels.

The tests have been made inside an "eject-chamber" that consists of five target panels surrounding the tractor-operating machine system. This must move forward on an horizontal surface (in asphalt) with a velocity between 2 and 4 km h^{-1} and meets a mixture of sand and stones. The P.T.O. speed is set on the value indicated by the manufacturer. A further panel is applied on the rear window of the tractor's cab, representing the target referred to the zone of the driver. The effectiveness of the protection of the flail mower is evaluated by observing the number and the entity of the impacts of the material against the targets. The target panels are represented by 2 m high, vertical wood frames, supporting Kraft paper sheets with a grain of 120 g m^{-2}. Two reference lines must be drawn on each panel: one at 200 mm and the other at 600 mm from the soil surface, in order to define three zones on the target (lower, medium and higher) as a reference for the evaluation of the impacts. The target are also divided, by vertical lines, in numbered sectors with a width of 1000 mm. The mixture used consists of a fraction of sand (50%) and two fractions of gravel respectively characterized by diameter between 8 and 16 mm (25%) and between 16 and 31.5 mm (25%).

Figure 5. The test material

The mixture, with moisture contents corresponding to the saturation point, must be positioned in conic piles with a volume of 10 l and a height of 150 ± 5 mm (fig. 5). The piles must be disposed on a line perpendicular to the advancing direction, behind the tested machine, at a distance of 2000 mm from the rear wall of the chamber. The reference standard defines the disposition and the number of target panels and of the piles of mixture, depending on the characteristics of the flail mower.

Two tests have been executed, with blades working height set at 50 mm from the soil. Each test consisted of two replications, always made on a new series of piles. After each replication, the impacts on the target panels have been observed and all the residues of the mixture accurately eliminated from the test surface.

Every perforation or tear outward observed on the targets Kraft paper is considered an "impact". The test is passed if the following conditions occur:

- the number of impacts does not exceed 2 in the medium zone (200 to 600 mm) of each numbered sector;
- no impacts occur in the higher zone of the eject chamber and on the target positioned on the cab's rear window.

In the case in which the results of two tests are uncertain, the conformity of the machine to the standard is decided on the basis of the results of a third test.

Results

The results of the tests for the measurements of the sound pressure levels generated by the flail mower are reported in the table 2.

Table 2. Results of the sound pressure level measurements

	Test	$L_{pC,peak}$ dB(C)	L'_{pA} dB(A)	Pto speed (min^{-1})	Δ□L dB(A)	K_1 correction dB(A)	K_2 correction dB(A)	L_{pA} dB(A)
1	Background noise with tractor and trolley	100.9	80.9	542	-	-	-	-
	Noise under working conditions without load	106.5	88.5	543	7.57	0.84	0.63	87.04
2	Background noise with tractor and trolley	101.4	80.8	542	-	-	-	-
	Noise under working condition without load	107.7	88.6	543	7.82	0.78	0.65	87.19
3	Background noise with tractor and trolley	100.9	80.9	542	-	-	-	-
	Noise under working conditions without load	106.5	88.7	543	7.81	0.79	0.64	87.24
4	Background noise with tractor and trolley	100.7	81.1	542	-	-	-	-
	Noise under working conditions without load	106.8	88.8	543	7.69	0.81	0.67	87.32
5	Background noise with tractor and trolley	101.0	81.1	542	-	-	-	-
	Noise under working conditions without load	107.3	89.0	543	7.94	0.76	0.64	87.60

It can be noticed that the L_{pA} values are always higher than the reference value of 85 dB(A). As consequence, the maximum L_{pA} value, equal to 87.6 dB(A) and its associated uncertainty must be indicated on the user manual of the machine and it has been necessary to determine the corresponding sound power. The results of the measurements of the sound power level are reported in the table 3, showing a maximum sound power of 104.58 dB(A). Such a value and its associated uncertainty must be reported in the user manual as well.

The presence of the tractor affected the measurements of both sound pressure and power generated by the flail mower, as testified by the high values of the corresponding correction coefficient (the maximum K_1 values are, respectively, 0.84 and 0.70 dB(A) for the sound

pressure and the sound power). On the other hand, as the tests have been executed under free noise field conditions, the background coefficient of correction, K_2, resulted below the standard's limit (respectively, 0.67 e 0.66 dB(A) for the sound pressure and the sound power).

Table 3. Measured levels of the sound power

Replication	L_p, dB(A)	Pto speed (min^{-1})	Correction (K_1) dB(A)	Correction (K_2) dB(A)	Surface (m^2)	L_w dB(A)
1	85.57	540	0.70	0.63	100.48	104.27
2	85.71	543	0.67	0.66	100.48	104.41
3	85.74	540	0.66	0.63	100.48	104.48
4	85.84	542	0.65	0.66	100.48	104.56
5	85.86	542	0.65	0.66	100.48	104.58

Finally, the data collected during the tests for the determination of the sound pressure underwent frequency analysis in $^1/_3$ –octaves that provided the behaviour of fig. 6: the contribution of flail mower to the sound pressure level is given by the difference between green and blue bars. It is more significant within the interval 200 to 630 Hz and shows a typical peak at 63 Hz, as, at 125 Hz, it could be determined by the resonance effect of the 63 Hz frequency.

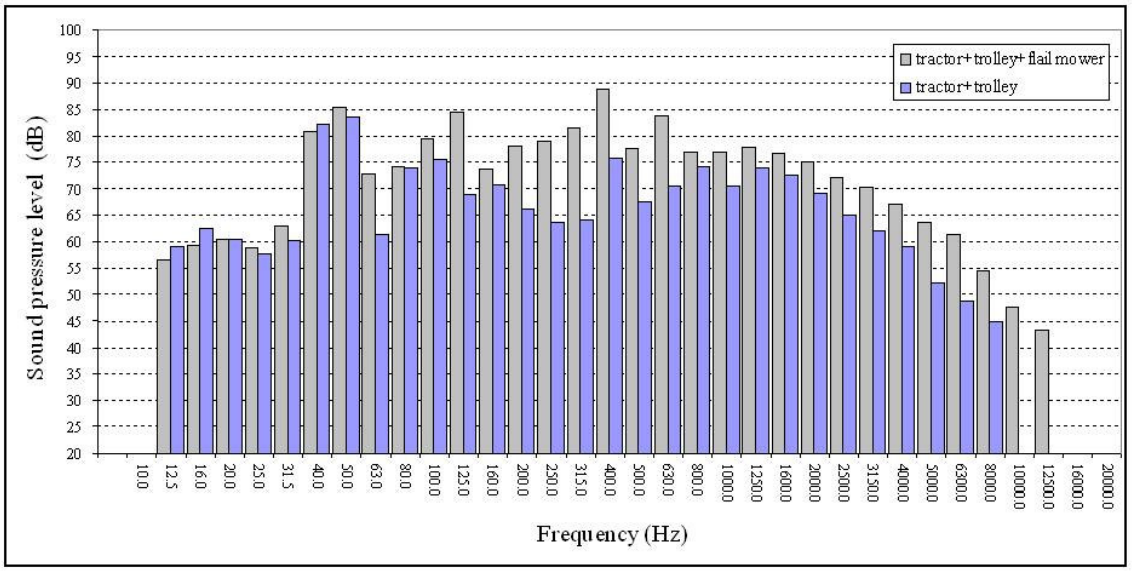

Figure 6. Frequency analysis in $^1/_3$ –octaves

As regards the suitability of the safety protections against the ejection of materials during the work, the results of both the tests showed that no impacts occurred on the higher zone of the target and on the panel on the rear window of the car, as the medium zone never evidenced more than two impacts in each numbered sector of the eject chamber. As consequence of these results, the protections are in conformity with the safety requirements of the EN 745:1999 standard and the flail mower passed the test.

The parking stability has been verified on the tilted plane described above: the flail mower has been parked on the tilted plane in the four different orientations, by progressively

rotating it of 90° (in the horizontal plane) and, as no movement has been observed, the test has been passed.

Conclusions

The present paper reports an example of the application of the standards requirements to the tests aimed at evaluating the operating machines from the point of view of safety. The tested flail mower resulted in conformity with the standards for the protection against the accidental ejection of materials (EN 745:1999) and for the parking stability (EN ISO 4254-1:2005). As to the sound pressure, the measured values exceeded the reference value of 85 dB(A) (EN ISO 4254-1:2005) and had to be reported on the user manual together with the corresponding sound power level.

As a consequence of the relevance assumed by the aspects of safety and prevention of accident in the work environment, the importance of such an activity is continuously increasing. In particular, when it is conducted in an official testing centre, it represents a guaranty for both the users (that can orientate their choices towards the most safe machines) and the manufacturers (often small manufacturers that could find, in the test results, suggestions for modifications and adaptations aimed at improving the quality of the machines). For instance, considering the observed dislocation of the impacts in the different sectors of the eject chamber, the presence of perforations in the front and side panels suggests some modifications in the design of the flail mower sides and of the lateral sledges, aiming at avoiding the presence of unprotected zones.

Furthermore, the high values of sound pressure and sound power generated by the flail mower seem to be mainly due to the blades bolted on the horizontal rotor and to their high rotation speed (1790 min^{-1}). Probably, such levels of noise could be significantly reduced if the tool-holder rotor, before its mounting on the machine, undergoes an electronic balancing aimed at reducing the level of vibration.

References

EN 745:1999. Agricultural machinery - Rotary mowers and flail-mowers – Safety.

EN ISO 3744:1995. Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane.

EN ISO 4254-1:2005. Agricultural machinery – Safety – Part 1: general requirements.

ISO 6926:1999. Acoustics - Requirements for the performance and calibration of reference sound sources used for the determination of sound power levels.