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Đuro Đaković RM-KA-02 Mine Flail Assessment Phase 1

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Executive Summary

This report summarises the results of an assessment of the RM-KA-02 midi-flail. The trial was designed to be the first phase of a three-phase assessment process evaluating handling and mobility characteristics and general performance capabilities. Phase two will be conducted in Sweden and will assess specific performance and survivability criteria. It is planned to conduct Phase three, assessing reliability and user acceptance tests in a mine-affected country at a later date

The trial was carried out in response to a request from the manufacturer, who saw the value of impartially testing the RM-KA-02 against internationally agreed criteria – CEN Workshop Agreement (CWA) on Test and Evaluation of Demining Machines.

Due to economic and time factors, the practice of carrying out a separate Pre-Trial Assessment (PTA), Mobility & Performance Trial and Survivability Trial was condensed into two phases (of which this report presents the findings from the first phase).

The results from the tests recorded in this report were only able to give an indicative summary of the abilities of the RM-KA-02 due to environmental and time constraints. Further testing in the next phase of the trial will be required to support these results.

Overall the RM-KA-02 showed that it could be operated safely and has the potential to carry out demining operations such as Vegetation Clearance and Ground Preparation. It is recommended that the RM-KA-02 progress to the second phase of testing to further assess performance against mine targets and also assess its survivability against specified mine threats.

List of contents

List of figures

List of tables

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1 Introduction

1.1 Background

As part of a Canadian co-ordinated test this trial was phase 1 of a three-phase trial to test the RM-KA-02 against the criteria laid down in the CWA (CEN Workshop Agreement) on Test & Evaluation of Demining Machines [1]. This phase of the trial concentrated on mobility and aspects of performance. Subject to the preliminary results of the trial the RM-KA-02 will be shipped to Sweden for further performance testing and also survivability testing. Finally, provision has been made to subject the RM-KA-02 to reliability and user acceptance testing in a mine-affected country at a later date.

1.2 Aim

The aim of the trial was to evaluate the performance and mobility of the RM-KA-02 under defined threat and terrain conditions.

1.3 Trial Objectives

The objectives of the trial were:

- To assess the mobility of the RM-KA-02.
- To make a “rule of thumb” assessment of the performance of the equipment under prescribed conditions and to estimate clearance rates of both mined and vegetated areas.
- From available information to make an estimate of the running costs and logistical support required for the equipment during operations.

1.4 Authority

As part of a Canadian lead multi-lateral ITEP test, QinetiQ was tasked to carry out the trials by the Department For International Development (DFID). The core trials team comprised of representatives from the Canadian Centre for Mine Action Technology, SWEDEC (Sweden), United States Department Of Defense and QinetiQ (UK).

1.5 Support Request

Đuro Đaković was tasked to supply a RM-KA-02 for test. The support required included operation, maintenance and spares throughout the trial.

2 Equipment under test

The RM-KA-02 humanitarian mine clearance machine, developed and produced by Đuro Đaković Special vehicles, is based on a tracked chassis, with total weight of approximately 12.5 t, protected from explosive blast by 10 mm ARMOX armoured steel plates.

It is a remote-controlled ground based system designed to safely clear small to dense vegetation and is claimed to neutralise all types of anti-tank mines (AT) and anti-personnel mines (AP) mines from off-road areas inaccessible to large area mine sweepers. The operator uses a portable control panel to remotely control the system.

The RM-KA-02 system incorporates improvements to the original RM-KA-01 midi-flail identified during field evaluations. It is based on a tracked chassis powered by a more powerful Perkins diesel engine with a 2000 mm wide detachable flail head, and a remote control subsystem. Blast and fragment survivability technology has also been integrated onto the chassis and includes blast shields and protected hydraulic lines and hoses. The system uses an industry standard quick detach mounting plate which makes it simple to remove the flailing head for maintenance or to mount any other standard material handling or earth moving implement.

Figure 2-1: Dimensions of RM-KA-02

3 Trials methodology

3.1 Location and personnel

The trial took place between 7th & 9th June 2004 at the test site of the Đuro Đaković factory in Slavonski Brod, Croatia.

3.2 Trial rationale

The rationale behind the trial was to provide an assessment of the mobility, functionality and general performance capabilities of the machine. This was not intended to be an exhaustive test providing comprehensive mine clearance data, but rather an indication of the suitability of the machine for operating in a field environment and as much information as possible regarding its limitations and capabilities.

It is being considered as phase 1 of a 3 phase test regime, as follows:

Phase 1 – mobility, functionality and general performance

Phase 2 – thorough mine clearance testing, under controlled conditions against a statistically significant number of targets, plus vehicle and operator survivability tests

Phase 3 – field testing over a period of several months, to provide realistic productivity and running cost information.

These 3 phases of testing are aligned to the recommendations under development in CEN WS12, which aims to provide agreed international standards for the testing of mine clearance machines. The intention is to conduct phase 2 of the tests at SWEDEC (Swedish EOD and Demining Centre) in Sweden. The details of phase 3 have yet to be finalised but should be conducted in conjunction with an End User (either a demining NGO or commercial demining company). This will ensure best possible use is made of the facilities available in each location, and that the machine is not put forward to the next phase of testing until it has been confirmed that it is ready and suitable.

3.3 Records

A trials plan and safety plan were prepared in advance of the trial. All trial activities were recorded on video and still photographs. Results of each test were recorded on trial performance sheets that have been retained by QinetiQ and are available on request.

4 Test procedure

Test procedure sheets were issued for each test, a summary of the tests is shown in Table 4-1 below. A description, summary of results and comments/observations of each test are detailed in section 5.

Test	Description	Category
A1	Weights & Dimensions	Mobility
A1a	General Dimensions	Mobility
A1b	Axle Weights	Mobility
A2	Handling & Mobility	Mobility
A2a	Turning Circle	Mobility
A2b	Travelling and Working Speed	Mobility
A2c	Slopes & Gradients	Mobility
A2d	Obstacles	Mobility
A3	Field of Vision	Mobility
A4	Remote Control	Mobility
A4a	Failsafe	Mobility
A4b	Controlled Shutdown	Mobility
A4c	Range	Mobility
A4d	Operational Control	Mobility/performance
A5	Ground Flailing	Performance
A5a	Speed versus Depth	Performance
A5b	Terrain following	Performance
A5c	Slope & Ditch Clearance	Performance
A6	Vegetation Clearance	Performance
A7	Logistics	Logistics

Table 4-1: List of planned tests

5 Results

5.1 Weights and Dimensions

5.1.1 General Dimensions

The following measurements were taken using a tape measure, a clinometer and a straight edge:

Measurement	Length/Angle	Verified by Trials Team
Overall length	5500mm	✓
Overall length of prime mover B4-L1203 RC	3880 mm	✓
Wheelbase (Length between front & rear axles)	2705mm	✓
Width between the external faces of the wheels	1785mm	✓
Width of flail header	2500mm	✓
Width of cut made by flail	2000mm	✓
Maximum depth of bite	> 200 mm	✓
Maximum working height of the prime mover	2 145 mm	✓
Swing of flail	up 15°	✓
	down 15°	✓
Ground clearance under belly of tractor	380mm	✓
Approach angle	35°	✓
Departure angle	43°	✓
Track contact area (tarmac)	2705 x 400mm	✓

Table 5-1: RM-KA-02 general dimensions

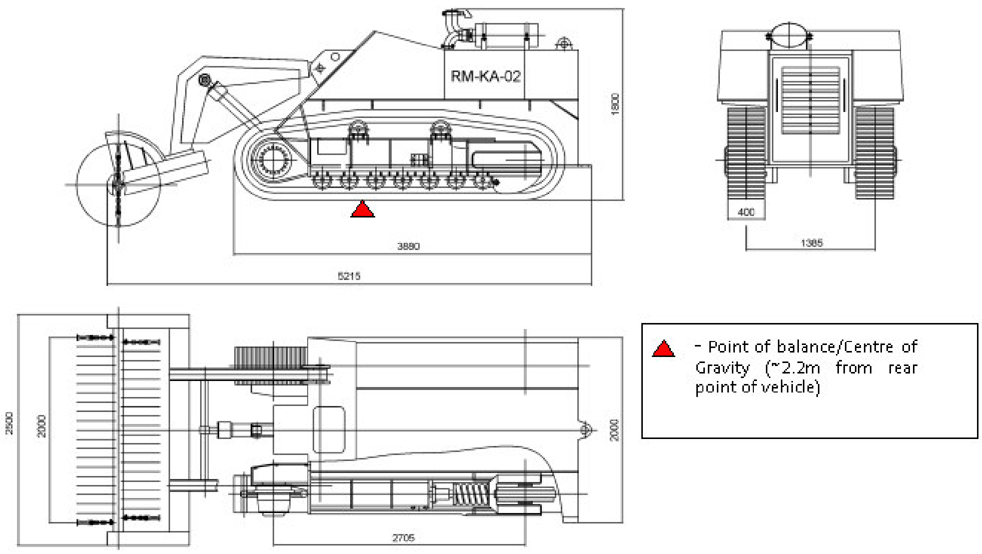


Figure 5-1: Dimensions of RM-KA-02

5.1.2 Weights

It was not possible to verify the vehicle mass due to time and budgetary constraints.

Gross vehicle mass (*Manufacturer's Data*)	12500kg

Table 5-2: RM-KA-02 mass

5.2 Handling and mobility

5.2.1 Turning Circle

The RM-KA-02 was parked on an area of level concrete. A container of salt was attached to the front left corner of the flail header, positioned so that salt would pour onto the ground directly beneath the outermost corner of the vehicle as it turned to the right. The vehicle was then driven slowly through 360° to the right using its maximum turning lock It was noted that since the RM-KA-02 was a skid-steer machine it could theoretically turn on its own axis.

Note: A second measurement, the Kerb to Kerb Turning Radius was not recorded however it appears on the diagram below as ØB.

The diameter of the circle of salt produced as measured as follows:

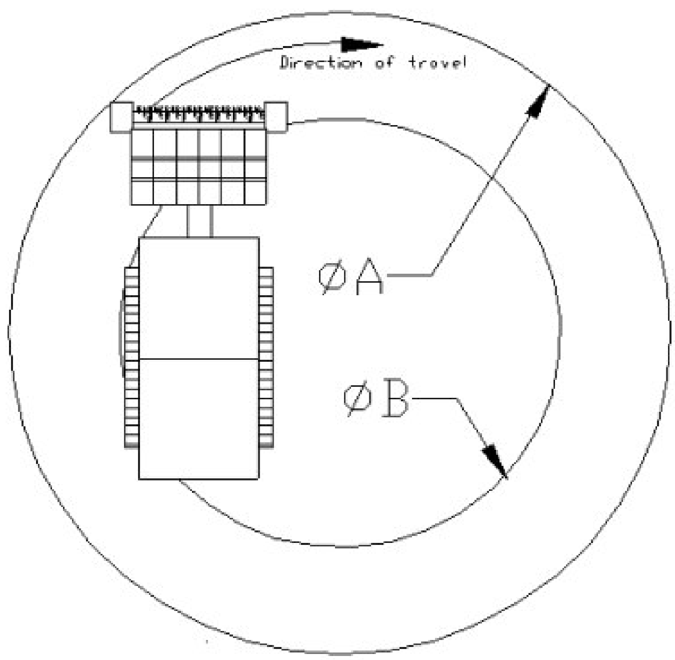


Figure 5-2: Turning circle of RM-KA-02

Direction	ØA	ØB (metres)
Forward right-hand lock	6150mm	Not measured

Table 5-3: Turning circle of RM-KA-02

Figure 5-3: RM-KA-02 completing turning circle test

5.2.2 Straight Line Speed and Braking

A dedicated Straight Line Speed and Braking test was not felt necessary since, as a remote controlled machine, it would be usually operated at a walking pace when manoeuvring outside of a mined area. However, the following measurements were recorded during the trial:

Transiting speed (to and from operations): >1.1ms^{-1}

Minimum set operational speed: 0.09ms^{-1}

RM-KA-02 has a hydrostatic braking system therefore if the system fails mechanically the brakes will engage due to lack of hydraulic pressure.

During the trial it was observed that the operator had good control whilst manoeuvring and braking.

5.2.3 Slopes and Gradients

The test slopes were located at the test site of the Đuro Đaković factory, which had sufficiently challenging hills. The hill sections were approximately 30m long consisting of hard packed gravel and topsoil. The ground was very wet due to the weather.

The RM-KA-02 was required to drive up these slopes, come to a complete stop halfway up the slope and then continue to the top of slope. The procedure was then repeated for the machine reversing up the slope.

RM-KA-02 was not required to operate the flail during this test.

The following results were obtained.

Gradient	Terrain	Result
23° - Driving forward & in reverse	Hard packed gravel and topsoil.	RM-KA-02 climbed the slope turned through 90° then flailed a 4.5m strip of medium vegetation. RM-KA-02 was able to maintain a controlled stop/start on this hill.
Progressively steepening hill (25° @ halfway point on hill, test concluded at 30°)	Hard packed gravel and topsoil.	RM-KA-02 progressed well up the hill, stopping periodically to show its hill start ability. It finally lost traction attempting to negotiate a log across the track. The gradient at this point was 30°.

Table 5-4: Results of the slope test

Figure 5-4: RM-KA-02 Climbing the second slope

5.2.4 Rough Terrain & Obstacles

No dedicated Rough Terrain & Obstacle tests were carried out due to time constraints. However, after the Slopes and Gradients test the operator demonstrated aspects of this by easily negotiating a 350mm-diameter tree trunk.

Figure 5-5: RM-KA-02 Crossing the log obstacle

5.3 Field of vision

The aim of this test is to assess all round driver visibility. Although an on-board camera is available for RM-KA-02 it was not demonstrated during the trial. Other than the camera, operators are reliant on their eyesight and the view from the safe area they are operating the remote control unit from. Therefore a Field of Vision test was not required.

5.4 5.4 Remote Control

5.4.1 Controlled Shutdown & Failsafe

Prior to evaluating the performance of the system under remote control, a basic check of its safety was carried out. This was done to ensure that the vehicle could be brought to a rapid and controlled shutdown. This was satisfactorily demonstrated with no apparent delay between the operator's commands and the vehicle responding. Based on the limited trial it appears that the RM-KA-02 failsafes to a state with the engine off and the brakes engaged.

5.4.2 Range

RM-KA-02 was placed at the end of a long straight road. The operator was then moved progressively further away. At each increment the operator was required to perform a series of movements with the RM-KA-02 (right & left turns, move the flail head up and down and make safe).

The stated maximum operating range of the RM-KA-02 is 800m. However, during the test it was found that at approximately 500m full operational control was not possible. One factor that may explain the difference in these measurements would be down to the positioning of the antenna on the prime mover. The antenna is mounted to the rear of the prime mover – Reduction in control only occurred when the prime mover made a turn. Whilst facing towards the operator the antenna is effectively masked by the rest of the machine.

5.4.3 Operational control

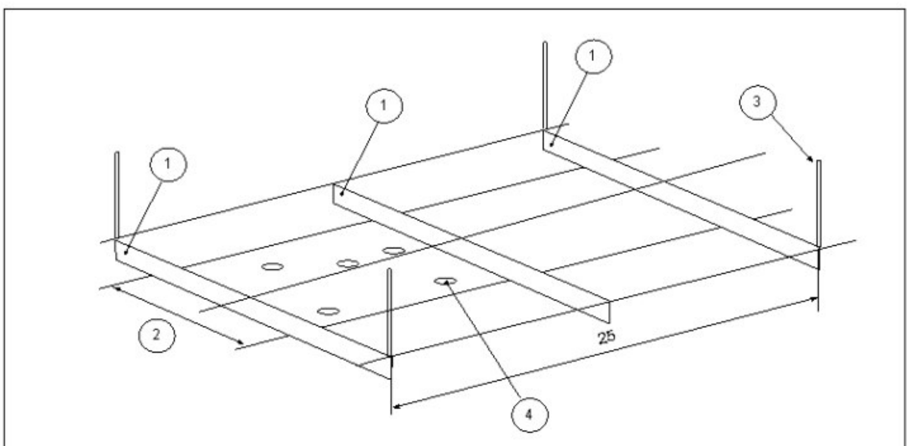
The feedback available to the operator was limited to visual observation hence precise operation was not straightforward at any great distance. This is common for any machine that operates visually and by remote control.

It was noted that forward speed can be set and then the operator could take his hands from the controls, only needing to move them back to make adjustments. This function is useful as it reduces stress on the operator. However, it should also be noted that this same feature is less useful if the operator becomes incapacitated and therefore cannot stop the RM-KA-02 by returning the controls to the neutral position.

The flail was also operated under remote control during the Ground Clearance tests described in section 5.5.2.

5.5 Ground Flailing

A series of 6m long lanes of flat ground were marked out for flailing. Each area had three hardboard sheets buried in it, 2.4m long by 0.3m wide, buried on edge flush with the surface, orientated across the direction of travel of the machine (see Figure 5-6). The intention of these tests was to flail each area at a constant depth (around 20cm) and to alter the forward speed of the machine with each test until the hardboard sheets indicated that forward speed was too high and hence obtain maximum forward flailing speed for the machine at that flailing depth (in that terrain).



1 Fibreboard
2. Track width
3. Marker poles
4. Surrogate mines (No mines were used in this test)

Figure 5-6: Layout of test lane

The boards should provide a clear indication of how deep the flail chains were cutting and whether they were achieving consistent cutting across the width of the flail. Previous tests on other machines had indicated that if flailing depth is too large, or forward speed too high or flail rotational speed too low, uneven flailing will occur and sections of the hardboard strips remain intact, whereas correct flailing will cut away an even depth of the boards across the entire width (see Figure 5-7 & Figure 5-8).

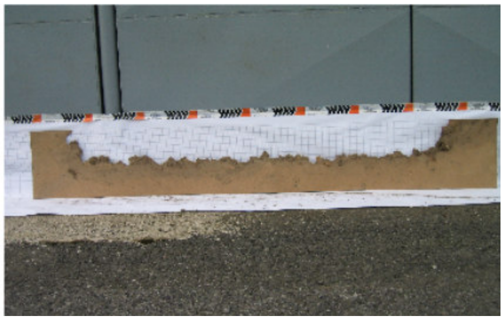


Figure 5-7: Example of a consistent cut across the width of the flail

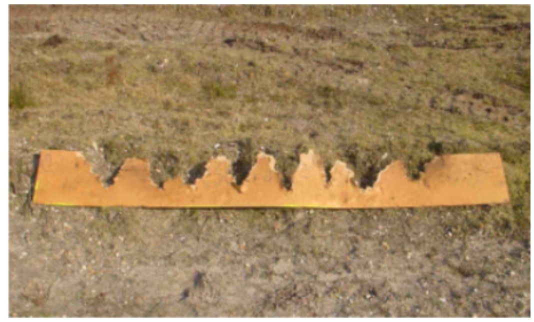


Figure 5-8: Example of an inconsistent cut across the width of the flail

Due to the heavy rains experienced in the region before and during the trial period it was not possible to complete the ground flailing tests as planned.

5.5.1 Speed versus depth

It was found that the test site was waterlogged. A run was conducted however as seen in the figures below the results were not ideal.

It should be noted that the ground in this test lane was very challenging and possibly more extreme than would be expected in an operational situation. The consistency of the soil was wet and clay based requiring a lot of energy per unit area of soil. The RM-KA-02 was either not able to maintain a slow enough forward speed or high enough flail speed to produce a constant depth of cut at ~200 mm. This resulted in several skip zones (see Figure 5-10).

Figure 5-9: RM-KA-02 at the start of Run 1

Figure 5-10: Run 1, Board 1

A second test area was located, however there was no time to dig in the fibreboards. The ground was less waterlogged and consisted of rocky topsoil. A 10m run was marked out for the RM-KA –02 to run through. In this soil the RM-KA-02 fared better producing a clearer cut measured at 200mm, although this could not be backed up by evidence from fibreboards – See Figure 5-11 & Figure 5-12.

Figure 5-11: RM-KA-02 in the second test lane

Figure 5-12: State of the ground after test run

5.5.2 Beat pattern

A test was conducted on the tarmac road on the way back from the first test field. The aim of the test was to measure the beat pattern of the flail hammers.

The RM-KA-02 was driven forward at a slow walking speed (3rd set speed) with the flail heads just touching the ground and a flail speed of ~600rpm.

There is relationship between forward speed, flail speed and density of flail chains on a flail shaft. An optimum beat pattern would leave spaces between the hammer strikes less than the smallest mine encountered in operations.

In the case of the RM-KA-02 the pattern left spaces of ~70mm x 70mm – Smaller than most common mines (but not all).

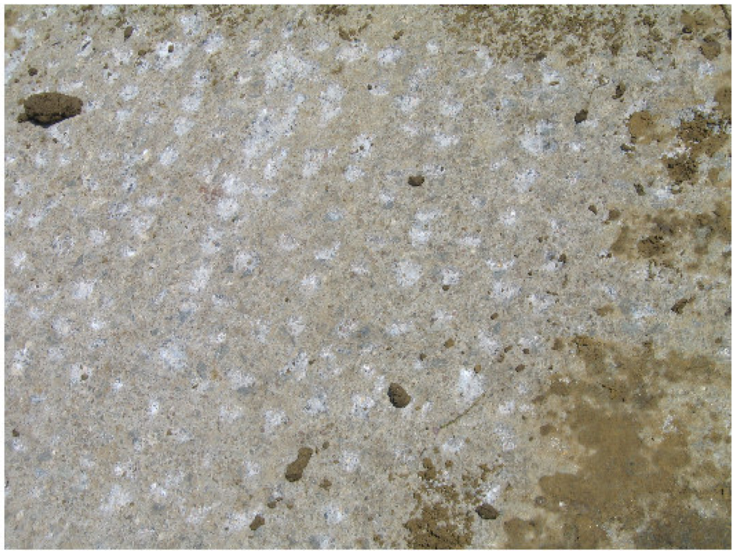


Figure 5-13: Beat pattern

Figure 5-14: Close-up of beat pattern

5.5.3 Terrain following

To test the operator's ability to accurately control the flail depth over variable terrain a run was conducted in the rocky soil whilst operating the RM-KA-02 at a distance of 60m. The lane had a small ditch across it of approximately 1m deep and 2m wide with gently sloping sides. The operator was able to show good control maintaining ~200mm depth at the start and end of the run. From inspection the whole lane looked well processed however without the fibreboards it was impossible to judge accurately to what depth the middle section of the lane was processed to.

It was concluded that when operating the RM-KA-02 at a "safe" distance of 60m it was difficult, but not impossible, to maintain a constant depth of cut. This is due in part to the RM-KA-02 having no depth control system.

5.5.4 Slope and ditch clearance

No dedicated slope and ditch clearance test was carried out although aspects of this were incorporated into Terrain Following and Vegetation Clearance.

5.6 Vegetation clearance

In many situations flails are used just to clear vegetation without engaging the ground and hence the ability of the RM-KA-02 to do this was assessed.

The test involved clearing a ~30m long strip of shrub, bush and small trees. The test run consisted of young trees and bushes with an average diameter branch at 0.5m high of 15mm.

The ground in the test lane consisted of a thick wet clay and gravel mix finishing with sandy hillock.

This level of vegetation posed little problems for the RM-KA-02.

Figure 5-15: RM-KA-02 at the start of the Vegetation Clearance Test

5.7 Logistics

It was not possible to gather any meaningful data on cost efficiency and reliability during the period of the tests. All that can be said is that during the trial period the RM-KA-02 required no repair or maintenance other than daily checks and cleaning.

5.8 Other Factors

The RM-KA-02 operates a two-stage automatic fire control/suppression system using a halogen substitute. The fire suppression system was not tested during the trial period.

In the event of a hydraulic failure the brakes will lock on and can only be released for an emergency tow-out by either attaching a portable pump to the system or disassembly of the axles in the middle of the minefield. This should be considered when producing Operating Procedures for this machine. This was not tested during the trial period.

Onboard cameras and skids for the flail head are available for the RM-KA-02 although they were not assessed as part of this trial.

6 Conclusions and Recommendations

6.1 Safe Operation

- Based on the limited trial it appears that the remote control system on the RM-KA-02 failsafes to a state with the engine off and the brakes engaged either by controlled shutdown or through loss of signal. This is considered safe for demining operations.
- The forward speed can be pre-set, the operator can then take his hands from the controls, only needing to move them back to make adjustments. It should also be noted that this same feature could cause a problem if the operator becomes incapacitated and therefore cannot stop the RM-KA-02 by returning the controls to the neutral position. This aspect of the remote control system should be considered when producing Operating Procedures for this machine.
- The RM-KA-02 operates a two-stage automatic fire control/suppression system using a halogen substitute. This would be considered as adequate for demining operations.
- In the event of a hydraulic failure the brakes will lock on and can only be released for an emergency tow-out by either attaching a portable pump to the system or disassembly of the axles in the middle of minefield. This should be considered when producing Operating Procedures for this machine.

6.2 Mobility and Transportability

- The RM-KA-02 is a compact medium sized flail. At 12500kg it is possible to transport it by truck.
- As demonstrated during the trial, with the correct training the RM-KA-02 showed good remote control ability limited only by the view of the operator.
- The maximum remote control range was measured at 600m with the flail unit pointing away from the operator. This was reduced to 460m with the flail unit pointing towards the operator (thus shielding the antenna). A taller antenna could extend range but 460m is adequate for most demining operations.
- The RM-KA-02 is a very mobile vehicle able to traverse slopes of at least 30° and challenging terrain such as waterlogged/boggy ground.

6.3 Performance

- The ground on the pre-prepared test lanes was far too wet for the machine to process however, in hard, stony ground (relatively dry) the machine seemed to perform adequately i.e. no skip zones detected at end of runs. Without the witness boards in place no conclusions can be made on this aspect of performance without further testing to confirm the results.
- Although the operator had good general control of the machine, the RM-KA-02 had no ground contouring system. Combined with this was the observation that at times the flail raise/lower control was too coarse i.e. too fast for fine control of the flail depth.

- It was noted that the RM-KA-02 was being operated at its lowest forward speed for flailing operations. It is understood that with an adjustment to the speed controllers on board a lower speed capability is attainable. Altering this speed controller should be considered for more challenging conditions.

6.4 Other recommendations

- At present access panels for maintenance and service are bolted shut. Quick release fasteners on daily maintenance points would make life easier but the bolts worked perfectly well.

7 References

[1] Draft CEN Workshop Agreement on Test and Evaluation of Mechanical Demining Machines – www.itep.ws

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