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TITLE

REVIEW OF CANADIAN ACTIVITIES ON MUZZEL REFERENCES SYSTEMS

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REVIEW OF CANADIAN ACTIVITIES ON MUZZLE REFERENCE SYSTEMS

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SUMMARY

Thermal deformations of gun/tank components and gun vibrations can affect the firing accuracy of modern tanks. To alleviate this problem, electro-optical gun muzzle reference systems (MRS) both static and dynamic (DMRS) have been designed to provide corrections to the computer generated signals responsible for fire control. This paper first summarizes the typical factors that induce firing inaccuracies and compares their magnitude. Then a discussion of the electro-optical approach used to sense the angular position of a gun and a description of the design of the static MRS developed in Canada follows. A review of the performances and advantages of the latest MRS version is also presented. Finally, an overview of the new DMRS research program will complete the paper.

1. INTRODUCTION

Although sophisticated, all tank fire-control systems rely on the assumption that the position of the main gun muzzle is precisely known from tank geometry and previous aiming adjustments. In fact, the accurate firing of a tank gun is essentially dependent on the angular offset between the gunner's line of sight and the gun's line of sight (Fig. 1). Unfortunately this offset is not always known precisely as demonstrated by a series of tests performed in Canada and similar investigations elsewhere. These tests revealed that thermal distortion can induce significant displacements of the gun muzzle from its presumed position. Vibration caused by tank movements can also generate substantial displacements that have to be taken into account in a fire on the move context. The factors affecting this offset can be thought of as acting in two planes: the vertical plane, in which the superelevation offset must be considered (Fig. 1), and the horizontal plane, in which the lead angle offset must be applied.

This impossibility to ensure highly accurate firing has led to the development by the Defence Research Establishment Valcartier (DREV) and Canadian industry of a few generations of MRS capable to correct gun pointing errors. All these MRS involve a laser diode transmitter/receiver mounted in the turret and a small mirror at the gun muzzle to reflect the laser beam. They are very user friendly and they make possible automatic line-of-sight boresighting with the muzzle and require minimum operator involvement. As such they can be used under battlefield conditions where a manual boresight would not be considered.

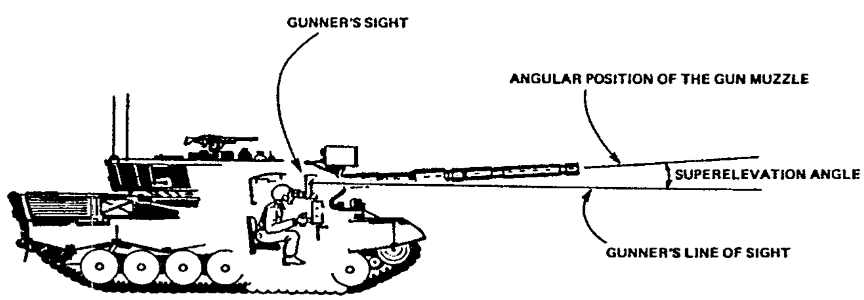

Figure 1 - Gun to sight alignment is essential for accuracy

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2. FACTORS AFFECTING FIRE-CONTROL ACCURACY

To understand the factors that can affect the firing accuracy of the tank gun , it is important first to have a good perception of tank components (Fig. 2). The barrel is essentially a cantilevered beam subject to thermal and mechanical forces. These tend to cause the muzzle, at one end of the beam, to move from its nominal location with respect to the other end which is attached to the trunnion. Solar heating, rate of fire and differential wind cooling of the barrel all contribute to thermal stress. The play in the cradle bearing allows the gun to deviate from the nominal location with respect to the turret. The trunnion angular sensor system mounted on the turret can also be a source of offset errors resulting from thermal drift and non linearity, as can the sighting system which is normally servo-controlled. To make matters even worse, the turret itself, which acts as a base for the entire sighting system, is subject to thermally-induced deformations which contribute to the overall offset errors. Therefore, all sórts of mechanical sources of error are present throughout all the links in the system comprising, not only the gun, but the entire turret and associated assemblies. All the previous sources of errors can be called static or quasi-static errors. There are also dynamic errors normally vibration related. The fundamental resonances of the barrel are of primary concern, whether they are caused by shock from the tank operation and travel, or from the effects on components due to turret and barrel relative motions. Dynamic firing effects primarily affect the barrel, although the barrel activating mechanisms are also involved. Along the well understood angle of departure errors which are correctable, there are also other systematic barrel deformations and vibrations as the projectile travels within the barrel.

Table I summarizes the typical error sources and provides an estimate of their magnitude (Ref. 1). These errors all contribute to changes in the nominal, theoretical relationships between components, allowing the gunner's line of sight to drift or jump in an unpredictable direction in relation to that of the muzzle. The total error may in certain instances reach 2 mils, thus seriously affecting the first-round hit probability, which nowadays is the name of the game in tank gunnery. Some of these effects deviate the point of impact from that anticipated in a detectable and correctable fashion, while others introduce apparently random errors. Those which are detectable or repeatable may be removed easily. Many detectable errors, for example those due to environmental conditions are normally corrected by the tank fire-control system that routinely senses and accounts for the target distance and movement, the tank velocity, the projectile velocity and the surrounding air velocity. Some of the random errors can be removed by using simple mechanical methods (Ref 2). This can also be done by a tank zeroing that locks-in corrections for the errors that existed at the time of zeroing. This gives the tank its best probability of hitting targets as long as those same conditions exist. As the conditions change, however, those locked-in corrections are no longer valid, and unless updated through the fire control solution, this can result in a decrease in accuracy. This is the problem that a MRS can solve.

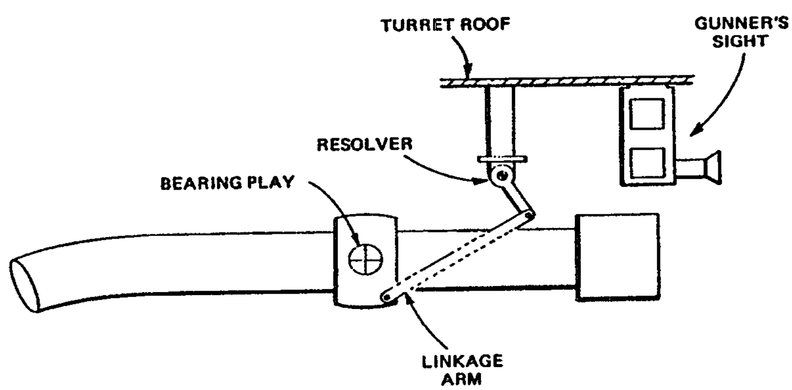

Figure 2 - Some mechanical sources of firing errors

TABLE I
Typical error sources and magnitude(From Ref. 1)

Variable	Magnitude (mils)	Cause
Barrel Deformation	0.5 to 1 0.1 per round 0.2 to 1	Thermal-environment Thermal-firing Mechanical stress Vibration
Barrel Position Sensor	0.01 per deg. C	Drift
Sight Mirror	up to 0.3	Deadband
Trunnion Play	0.2	Mechanical stress
Turret Distortion	0.1 to 0.5	Thermal Mechanical stress Vibration
Other Components Distortion	0.1 to 0.5	Thermal Mechanical stress Vibration

3. THE CANADIAN MUZZLE REFERENCE SYSTEM

3.1 Laser-projector MRS

An MRS is an is a system that optically senses the gun muzzle position and provides correction to the computer generated signals responsible for fire control. Several optical techniques including reference light source, collimator, retroreflectors or laser projectors have been explored so far for the design of a gun muzzle sensor. The Canadian MRS belongs to the laser-projector category. The technique used is based on the use of a solid-state transmitter that interrogates a mirror located at the muzzle end and a detector that measures the return beam position. Figure 3 presents a generic MRS geometry. The transmitter is an optical projection system which sends a collimated beam of light from a laser diode source to the muzzle mirror, where it is reflected back into the aperture of the receiver. The receiver is basically a camera which focuses the collimated beam onto a position sensing detector in the focal plane of the camera lens. As the tube bends or other errors are introduced into the geometry, the angular motion of the beam causes the focal spot on the position-sensitive detector to translate linearly.

3.2 Automatic MRS

MRS may be considered to be either manual or automatic in operation. The Canadian MRS is automatic and this makes possible to obtain high performances and ease of use both in the initial alignment and during the continued update. To be automatic appears essential when it is recalled that at the time just before firing, when the boresight really must be optimal, there is the greatest effort loading on both the fire control system, and on the crew as well. The benefit of an automatic MRS are numerous and include: 1) ability to verify boresight immediately prior to engagement and between rounds, 2) high accuracy not attainable with human involvement, 3) consistency independent of user skill or abilities and 4) no operator induced variability in combat.

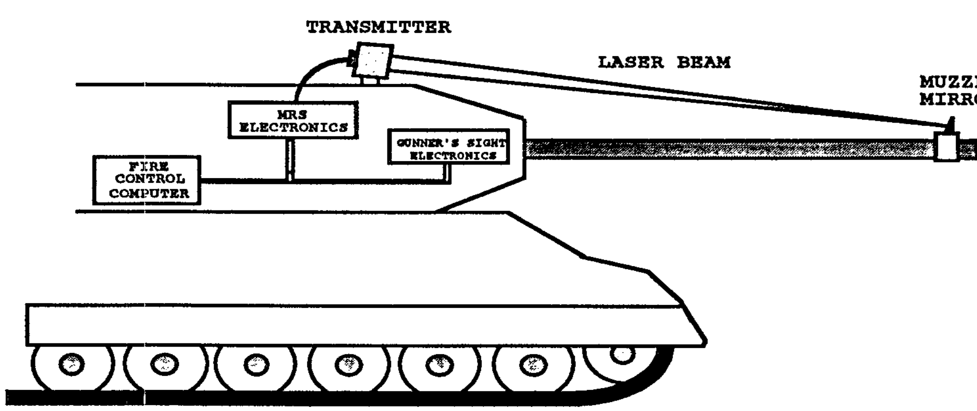

Figure 3 - Laser Projector MRS

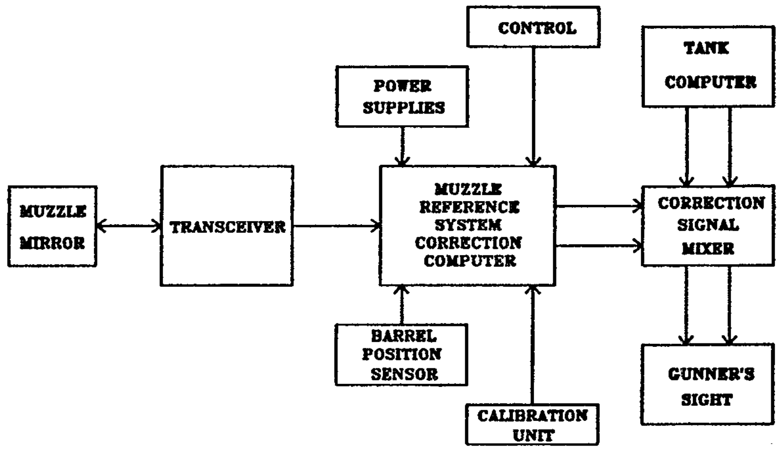

Figure 4 - MRS block diagram

3.3 Principle of Operation

The principle of operation of the Canadian MRS consists in measuring the angle of the gun muzzle and adding a supplementary correction to the two ballistic correction signals (superelevation and lead angles) that are generated by the fire control computer and sent to the sight. Both the transmitter and the receiver are mounted inside the turret directly attached to the gunner's sight. The displacement of the laser beam at the detector is directly proportional to the angular deflection of the muzzle relative to the gunner's sight, this being valid only for a specific angular position of the gun called the MRS reference angle. Operation of the system proceeds as follows: when the gunner wants to compensate for the error cumulated after the fire-control computer solution, he slews the gun in elevation across the MRS angle. At the precise instant that the gun is passing across the MRS angle, as detected through interfacing to the gun angle transducer, the return beam provokes the position detector to generate signals proportional to the deviation caused by gun droop and other error that had cumulated after the fire-control computer solution. An MRS electronics box processes these signals, derives elevational and azimuthal corrections and stores them in memory so that they prevail within the fire-control system as long the gun does not cross over the MRS angle again and new values for the corrections become available.

3.4 Block Diagram

A block diagram of the latest version of the Canadian MRS is shown in Fig. 4. There are three major sub-systems: a) an IR laser transceiver, b) a muzzle mirror and c) the processing electronics. The transceiver consists of an IR laser transmitter and a receiver, both using a common optics. The transmitter is composed of a pulse generator that drives an eye-safe laser diode. Figure 5 shows the laser source illuminating a square diaphragm aperture. The square beam, so defined, is focused by the lens onto the muzzle mirror. The transmitter being installed within the turret a periscope is used to redirect the laser beam towards the mirror. The mirror, in turn, reflects the beam back through the periscope and lens to a beam-splitter, from which a portion is reflected to a quadrant detector. The image of the square aperture which is reconstituted on the detector is shown in Fig. 6. The signals generated by the individual elements of the quadrant detector are combined, in a simple relationship, to provide correction signals for elevation and azimuth. The processing electronics is based on a microprocessor system that processes the signals coming from the receiver, derives elevation and azimuthal corrections and stores them in memory. A barrel position sensor detects when the gun crosses over the MRS angle and a correction-signal mixer permits to add the MRS corrections to the superelevation and lead signals coming from the tank fire-control computer and going to the sight electronics.

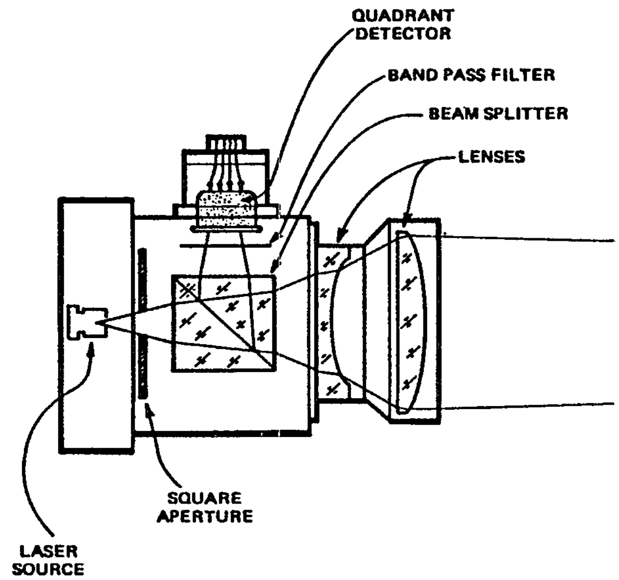

Figure 5 - Optical layout of the MRS transceiver

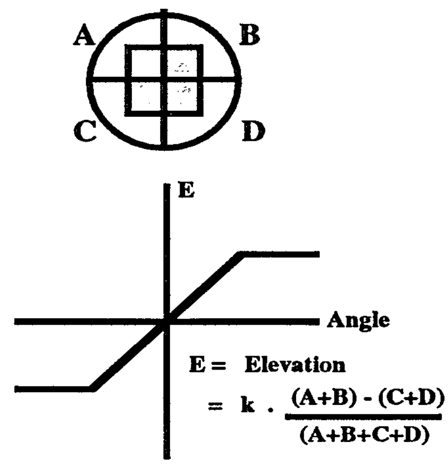

Figure 6 - Image of the return beam and angular transfer curve

3.5 Configuration of the MRS on the Canadian Leopard C1 tank

Based on the concept described above an MRS laboratory model was built and evaluated by Defence Research Establishment Valcartier (DREV). The concept appearing promising, an advanced development model (ADM) was built by industry based on a transfer of technology from DREV to Hughes Leitz Optical Technology, Canada. This ADM MRS was also thoroughly evaluated by DREV and a few deficiencies were identified. Following this evaluation, a second contract was awarded to Hughes Leitz Canada to produce an advanced engineering model (AEM) of the MRS. This AEM MRS was delivered to DREV in 1989 and its electro-optical performances assessed (Ref. 3). The results shows that the integration of the AEM MRS into the Leopard C1 has been successfully carried out with the system meeting all the technical specifications relative to thermal stability, linearity and range of corrections. The evaluation made also possible to identify a few remaining minor mechanical modifications to be implemented on the AEM. These modifications are presently being implemented.

In the AEM MRS the transceiver is attached directly to the Leopard C1 gunner's sight and is fitted with a periscope that goes through the turret roof and redirects the field of view toward the gun. This approach solves many problems identified in the earlier MRS versions. The gunner's sight had to be modified by incorporating additional mounting bosses to support the transceiver body. The external part of the periscope is protected by an armored cover rigidly mounted to the turret roof . When referencing, an armored door is opened but without changing the environmental seal of the internal components. This shutter is manually activated from inside the tank by turning a knob. The principle of operation of the AEM MRS transceiver is essentially identical to the one previously described.

The muzzle mirror (Fig.7) has been developed at DREV. The mirror itself is adjustable and machined out of a standard ball bearing whereon a flat surface has been machined. Spherical symmetry ensures maximum stability against vibrations induced by firing the gun. The mirror mount is machined out a solid block of steel. It is securely clamped to the gun muzzle, held into position by two flat surfaces, two references pins, which match with two small hole drilled in the gun barrel, and three bolts.

The AEM uses a digital angle encoder to sense the gun barrel elevation. An angular resolution of ±0.04 mils is thus obtained. The electronics assembly including both an electronics and a control box is located inside the turret. Based on microprocessor technology the electronics performs all the functions described earlier, namely the correction computing, the laser diode control, the MRS reference angle sensing and the interface with the tank fire control computer and the other MRS components.

A calibration console can also be connected to the MRS for initial setup. It displays data for aligning the system and subsequently establishing the reference "zero" position; that is, the angular relationship between the gun and the MRS mirror when no correction is made. The calibration console analog display is made of an array of light emitting diodes which are microprocessor driven to indicate the MRS alignment. Both a high and low range are available to provide an extended reading range at a greater resolution.

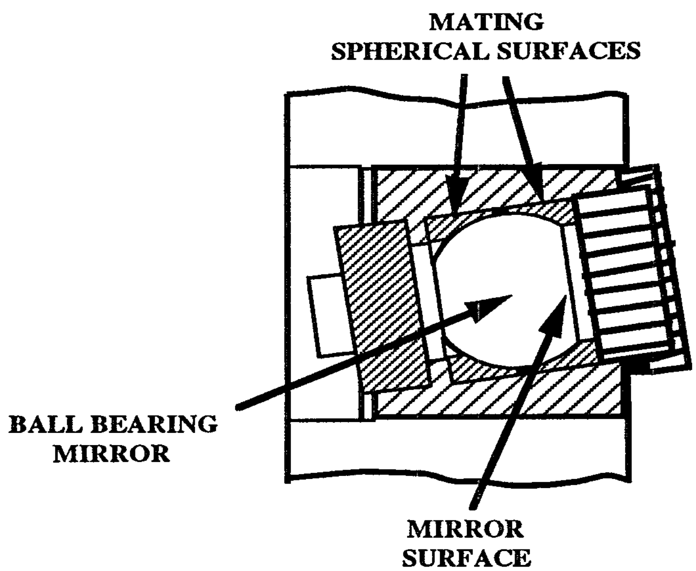

Figure 7 - Sectional view of the mirror assembly

3.6 Performances

The AEM MRS has been designed to measure angle changes between the muzzle and the gunner's line of sight to a range of 3 mils in elevation (-2 mils to + 1 mil) and ± 1 mil in azimuth with an accuracy of ± 0.1 mil. Figures 8 and 9 show respectively the measured MRS correction signals in elevation and azimuth as a function of the pointing error of the gun. The measurements can be compared to the ideal characteristics (straight lines). Implicit in MRS operations is the requirement that the MRS mirror remains stable with respect to the gun axis for extended periods of time and this, despite road vibrations and gun firing. Tests involving extensive gun firing have been run to evaluate the stability of the mirror relative to the gun barrel axis. Cumulative effects as a function of the number of rounds was one of the critical issues. Figure 10 shows the overall stability (mirror + mount) in elevation of the MRS mirror where both real (APDST) and practice (STUP) rounds were fired. A stability performance better than ± 0.06 mil was measured.

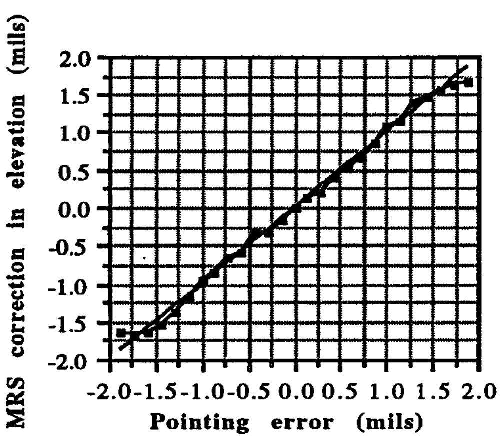

Figure 8 - MRS correction in elevation

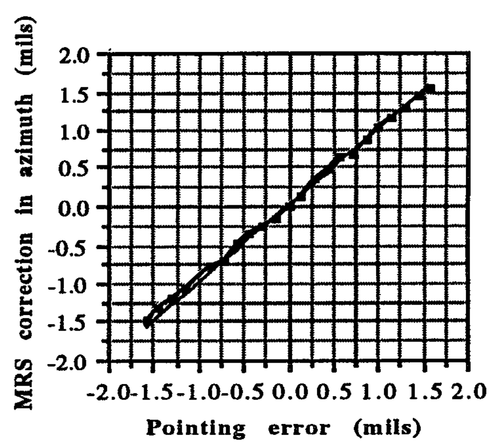

Figure 9 - MRS correction in azimuth

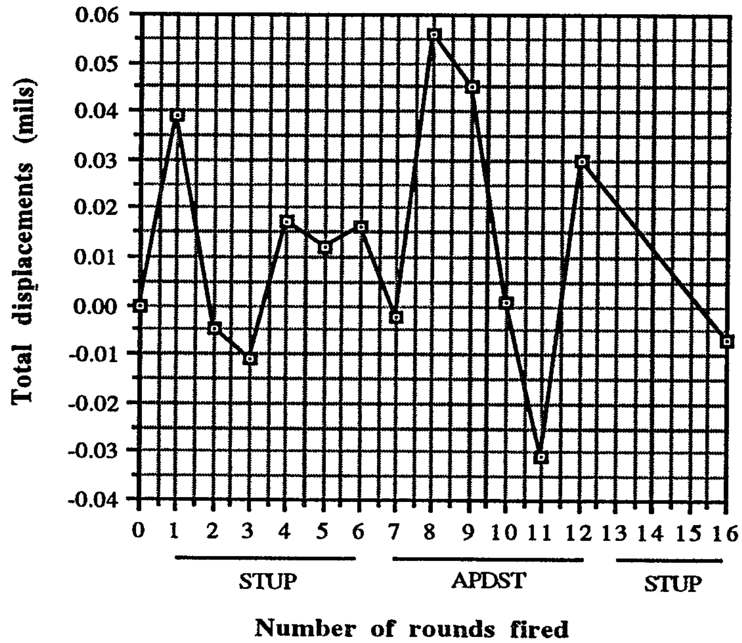

Figure 10 - MRS mirror stability

4. DYNAMIC MRS

The AEM MRS that has just been described provides corrections for a broad range of static/quasi static errors. These include barrel deformations, barrel position sensor linkage drifts, turret deformations and gunner's sight rotations. On the other hand, the barrel vibrations present during tank travel can not be precisely measured and corrected with a standard MRS because only a single point is sampled during a reference.

A dynamic MRS (DMRS) which continuously monitors the gun muzzle position and provides corrections can remove the limitations of the standard MRS and permit to achieve accurate fire on the move. Figure 11 depicts a dynamic MRS concept with reference information generated by two transceivers. One like the AEM MRS is fully integrated within the tank gunner's sight, the other is located at the base of the barrel continually monitors the barrel dynamics for all barrel angles. The principle of operation of the DMRS is essentially the same as the AEM one with three exceptions: 1) it operates at a much higher sampling frequency to measure dynamic effects, 2) an MRS reference angle detector is not required since the barrel is tracked and 3) additional algorithms are required. On the other hand, the DMRS can be based on the existing AEM MRS hardware and a future system will eventually combine an MRS and a DMRS sharing common mirror mount, interfaces and processing electronics. A research and development contract for the design and manufacture of a DMRS has recently been awarded to Hughes Leitz Optical Technologies Ltd. Canada by the Canadian Department of National Defence. A DMRS prototype has been built and the first field trials are scheduled for November 1993.

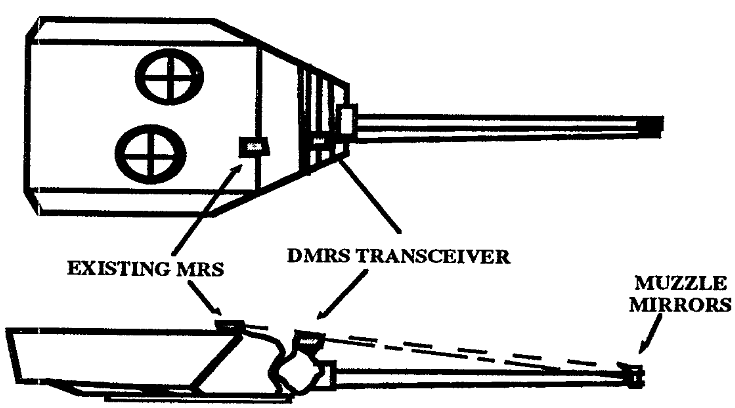

Figure 11 - Combining MRS and DMRS concepts

5. CONCLUSION

The DREV research and development activities on the MRS and the successful transfer of technology contributed to fostering a Canadian industrial capability. The current MRS provides corrections for pointing errors of the tank gun over a range of 3 mils total in elevation (-2 mils to + 1 mil) and ± 1 mil in azimuth within a precision of at least 0.1 mil. It is very user-friendly as it makes possible automatic line-of-sight boresighting with the gun muzzle and requires minimum operator involvement. It can be used under battlefield conditions where a manual boresight would not be possible. The advantages of the MRS are numerous; the improvement in first round hit probability is the prime one, but significant reductions in training and ammunition requirements as well as increased user confidence in the tank are also important. The MRS provides corrections for most static/quasi-static errors but still lacks the capability to compensate for barrel vibrations associated to fire on-the-move scenarios. This capability will soon be provided by a combined MRS/DMRS system that will provide complete corrections for a broad range of errors and full dynamic operation as well.

The current MRS is configured for the Canadian Leopard C1 main battle tank, but can be modified to suit a variety of tanks as an externally-mounted device or for integration into a gunner's sight.

6. REFERENCES

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