Incident Technical Report: Gear Wear Progression in Starboard Gear Train MG-5025A of Naval Vessel INS Haifa

Executive Summary

This report documents a progressive tooth-wear event that developed in the MG-5025A marine reduction gearbox installed in the propulsion train of INS Haifa. Baseline “Healthy” recordings were collected in February 2023 (with no abnormal indications through 8 April 2023). The first onset of wear was detected on 9 April 2023 and was tracked across 35 sequential wear cases through 15 June 2023, when elevated noise and vibration culminated in a functional failure that necessitated shutdown.

Monitoring used accelerometers placed on gearbox housings adjacent to the input and output shafts, sampling at 50 kHz for 60-second windows per record. Recording intervals followed the actual time stamps in the site Database log; per session we indicate whether records were back-to-back (≈1 minute apart), spaced by minutes, or collected in morning/afternoon/evening clusters.

Across April‑June, crews consistently reported louder gear noise under steady speed and a gradual rise in overall vibration level. Time-domain RMS, trended upward in step with the Wear Case 1 → 35 progression. The final day (15 June) showed a marked jump in amplitude and transient impulsive responses consistent with severe war liberation on a loaded flank, followed by immediate operational withdrawal.

Vibration signal processing and Image processing where preformed for analysis. The gearbox transmission lubrication in service was 2640 semi-synthetic, 15W/40 viscosity. All signals were record at speed 45 rps and 15 rps.

System Description

Vessel and Transmission: INS Haifa employs a conventional marine propulsion train. The subject gearbox is an MG-5025A naval reduction gear, configured as part of the ship’s main gear transmission. The investigated component is the primary reduction gear pair (driving gear and driven gear).

Lubrication: Sump and spray lubrication with 2640 semi-synthetic (15W/40) oil maintained to standard naval cleanliness targets. No bulk oil temperature logging was available for this investigation period.

Operating Conditions: Data were acquired at two steady speeds: 45 RPS (Full speed) and 15 RPS (Minimum).

Instrumentation & Acquisition: Two industrial accelerometers mounted on the gearbox casing near input and output shafts. The accelerometers direction measurements were at the gravity direction. 60-second time records, 50 kHz sampling rate.

Imaging: Following each measurement day, tooth-flank photographs were taken using a camera integrated with the inspection microscope available in the lab (images archived in the shipyard file and referenced internally to the daily session). Images served as qualitative corroboration of wear evolution (Healthy teeth → micro-wear → macro-wear).:

Failure Progression

February 13–28

At those days, Multiple records were taken at both speed: 250 records 45 RPS and 250 at 15 RPS. Within each date the team often collected back-to-back records (≈1-minute gaps) and short brakes spaced by 2–10 minutes, extending over one to several hours depending on ship activity. Across these February sessions, audible gearbox noise was steady and low, overall vibration level, Root Mean Square (RMS) and Frequency Modulation Energy (FME) remained low within measurement repeatability, and impulsive activity was negligible. No data were collected in March; no abnormal reports through 8 April 2023, which we retain as "Healthy" in the event timeline.

April 9

At this day, tiny teeth modifications were appeared in the pictures, may look as early smear marks without discrete pits. The first departure from baseline emerged at 45 rps with two clusters: a midday series (12:22–13:09) and an evening series (17:47–18:20). Individual 60-second records were frequently taken one minute apart, with short gaps of 5–9 minutes. Crew did not noted any abnormal . Time-domain and spectral metrics did not showed any change (RMS for time domain and FME for spectral domain) and sporadic high-crest impulses, hinting at the onset of micro-scuffing on a loaded flank. A short 15 rps diagnostic set complemented the 45 rps runs.

April 10

A longer campaign at 45 rps spanned 10:54–19:40 in three blocks separated by routine operations. Many records were back-to-back (≈1 minute spacing), others 5–15 minutes apart. Audible load-dependent noise grew more prominent, and vibration RMS drifted further upward. Intermittent short-duration impulses appeared more frequently in the time traces, consistent with incipient micro-pitting nucleation superimposed on scuffing. Low-speed checks at 15 rps echoed the same qualitative growth. Images showed more defined smear bands with a few tiny matte specks beginning to localize near the dedendum.

April 13

Evening measurements at 45 rps from 17:41–18:12 (records mostly 1–6 minutes apart). The crew commented that the previously subtle noise now presented as a persistent hum with occasional roughness. RMS increased modestly; impulsiveness ticked up relative to April 10. Images suggested early pit coalescence limited to one quadrant of the driven gear.

April 16

Midday (11:32–12:04) and late-afternoon/evening (17:01–17:29) 45 rps sets, with back-to-back pairs and 3–10 minute intervals. The audible harshness was now easier to provoke, and the time records showed more frequent, shallow impacts (short bursts within the 60-s windows). As a cross-check, 15 rps samples again reproduced the pattern at lower energy. Tooth-flank photos captured speckled pitting propagating along the primary contact path.

April 18

A compact series at 45 rps (13:08–13:35). Despite the shorter session, both crew feedback and time-signal amplitudes showed a clear step vs. April 16. Visuals confirmed pit density growth, with a few pits starting to link.

April 19

Two 45 rps clusters—midday (13:11–13:39) and evening (19:13–19:42)—provided good repeatability. Spacing within clusters remained near 1 minute with occasional 6–12 minute gaps. Operators reported distinct gear note roughness during the evening set. Time-domain envelopes showed longer intermittent bursts indicative of micro-to-macro pit transition on a single flank sector. Images showed pit coalescence with a slightly undercut edge on one macro-site.

April 20

45 rps recordings 12:09–12:37, tightly spaced (1–8 minutes). The overall RMS trend continued upward, with infrequent higher-amplitude spikes suggesting debris circulation. Imaging captured fresh bright spots adjacent to existing pits.

April 23

Three staged sets at 45 rps: midday W344 (12:25–12:50), late afternoon W378 (17:15–17:38), and night W400 (21:00–22:22). Within each, many records were back-to-back; between sets the gaps were hours. The day documented a material progression: from earlier roughness to audible rasp, with time-signals showing more frequent impulsive sequences and longer durations. Tooth images revealed multiple macropits on the driven gear's working flank and debris scuffing trails in the lubricant film.

May 1

Wear Cases 14–15. Two distinct 45 rps clusters: 12:24–12:49 (early afternoon) and 20:01–20:23 (evening). Short intra-cluster gaps (≈1–6 minutes). Crew noted that once warm, the gearbox produced pronounced chatter-like bursts during steady speed holds. Time-series showed taller peaks with higher crest factor, consistent with macro-pit edge shedding.

Imaging corroborated pit edge breakout on one tooth and micro-scoring tracks aligned with sliding direction.

May 2

45 rps 13:19–13:43; several back-to-back records. RMS and impulsiveness both increased relative to May 1 evening. Photos showed pit field expansion across adjacent teeth.

May 3

45 rps 13:51–14:17. Operators emphasized a louder broadband hiss/rasp overlaying the gear note. Time-signals exhibited recurrent impact packets lasting longer within the 60-s windows—evidence of repeated debris strikes.

May 7

Morning 45 rps block 11:29–11:59 (dense sampling), and evening block 16:50–17:15 (again, many back-to-back records). Both sessions captured clearly audible harshness and further RMS growth measured at the output casing sensor. Imaging indicated new spall lips and secondary cracking at prior pit rims.

May 10

45 rps 18:51–19:18 with repeated one-minute spacing. The time records contained several high-amplitude impulses strong enough that watchstanders recommended continued close monitoring and scheduling contingency for restricted-speed transits.

May 14

Afternoon/early-evening 45 rps 16:39–17:39 with 1–8 minute gaps. Audible roughness was now persistent at steady speed. Time-domain data showed clustered impacts that repeated across multiple records, consistent with one dominant macropit and two growing sites on neighboring teeth. Images confirmed coalesced macropitting on the primary contact zone.

May 23

45 rps 17:36–17:59. Short session by necessity; nevertheless, RMS and peak metrics exceeded those of May 14 by a small but repeatable margin. Visuals showed debris streaking downstream of the largest pit.

May 24

45 rps 18:52–19:16 with multiple back-to-back records. Crew again reported high noise; time-series reflected frequent, medium-height impulses suggestive of continued pit growth rather than a brand-new defect.

May 30

45 rps 17:27–17:54. The character of the signal shifted toward more continuous roughness, i.e., an elevated baseline with many superimposed smaller impacts—typical of widespread surface distress.

May 31

45 rps 19:22–19:47. Several impulses within each 60-s record reached new peak levels, although still intermittent.

June 1

45 rps 11:45–12:09. Compared to May 31, overall RMS rose again and the interval between major impacts shortened, consistent with larger damaged area per rotation.

June 4

A brief morning confirmation at 45 rps (09:19–09:20) followed by an evening campaign 18:25–18:48 at a more degraded state. The evening time-records showed dense impact trains and sustained roughness throughout each 60-s window. Tooth imagery indicated pit-field coalescence into elongated spalls along the line of action.

June 7

45 rps 15:22–15:44. Multiple impulses per record now reached consistently high amplitudes, aligning with operator reports of very loud gear noise.

June 8

45 rps 12:11–12:33. Another step up in both peak and crest factor, with little “quiet” time between impact groups in the 60-s windows. Images showed material breakout across the prior spall edge on at least two teeth.

June 9

45 rps 16:44–17:15. By this date, the roughness was readily audible on deck near the gear space. The time-signals contained wide, high-energy impact packets, pointing to debris recirculation and further loss of flank material.

June 11

45 rps 14:16–14:41. Continued RMS escalation and repeatable impact cadence were recorded; tactically, operations were already adapting to minimize exposure time at higher speeds.

June 13

45 rps 14:32–14:53. The gearbox presented persistent harshness with near-continuous micro-impacts, suggesting multiple active spalls distributed along the main contact path. Visual inspection showed spall growth crossing into adjacent flank areas.

June 15 – Failure day

A compressed sequence at 45 rps (10:19–10:44) captured the terminal stage. Records, spaced roughly 1–8 minutes, showed:

- A sharp jump in overall vibration and repeated very high peaks within each 60-s window,
- Longer impact trains with brief lulls, and
- Audible grinding/rasping reported by the watch.

Operations were halted following this sequence. Post-run imaging documented fresh, large spall edges and heavy debris scuffing, fully consistent with a functional failure of the affected gear flank.

Investigation Findings

1. Onset & Growth. The gearbox remained Healthy through 8 April 2023. Initial wear appeared on 9 April (Cases 1–2) and progressed steadily through 35 cases to a failure condition on 15 June.
2. Symptom Evolution. The progression followed a classic path:
   - Early: mild RMS increase and occasional impulses (micro-scuffing and pit nucleation).
   - Middle: sustained RMS growth with frequent impulses (pit growth/coalescence; debris circulation).
   - Late: high RMS with dense, tall impact trains (macropitting/spall propagation leading to flank material loss).
3. Speed Regimes. The trend was present at both 45 rps and 15 rps, with higher absolute amplitudes at 45 rps but qualitatively similar features at 15 rps—useful for controlled diagnostics alongside ship activity.
4. Recording Protocol (as executed). Each record was 60 s at 50 kHz. Dates show back-to-back one-minute records inside clusters, short 2–10 minute gaps during continuous sessions, and multi-hour gaps between dayparts. These actual intervals (as reflected in the Database time stamps) were sufficient to resolve step-wise degradation without masking transient changes.
5. Imaging Corroboration. Daily camera-through-microscope photos tracked flank condition from smearing to micro-pitting, then macro-pit formation and finally extended spalling by mid-June; this aligned with the growing noise and impact content in the time records.

6. Likely Mechanism. The evidence supports progressive surface distress on a loaded flank—scuffing → pitting → macropitting/spall—likely accelerated by local film breakdown and debris re-entrainment. Alignment or load-sharing imperfections may have concentrated stress on a sector of the driven gear, enabling rapid pit coalescence once nucleated.
7. Contributing Factors Considered.
8. Lubricant: 2640 semi-synthetic 15W/40 in use; no anomalies were recorded in this investigation, but contamination and film thickness under local sliding are potential accelerants.
9. Operating Profile: Repeated starts/halts and dwell at fixed speeds can amplify contact pattern persistence, accelerating localized damage once initiated.

Recommendations

1. Condition-Based Monitoring (CBM) Standard.
   - Protocol: Retain 60 s @ 50 kHz. During maintenance windows, collect three back-to-back records at each of 15 rps and 45 rps, repeat every 10–15 minutes for an hour when a trend is suspected; otherwise a two-cluster approach (midday/evening) is sufficient.
   - Metrics: Track RMS, peak, crest factor, and an impulsiveness index per sensor. Alerts when RMS > baseline + 6 dB or crest factor increases by >25% over a 7-day rolling average.
2. Imaging Routine. After each monitoring day, capture tooth-flank images at identical magnification and lighting, referencing the same tooth indices, to maintain comparable visual evidence of progression.
3. Rapid Escalation Criteria. If multiple 60-s records within a day show repeating high-amplitude impact trains (qualitatively similar to 6–15 June patterns), reduce operating time at 45 rps and plan immediate inspection.
4. Alignment & Contact Pattern. Perform a contact pattern check at the earliest dock opportunity. Minor contact correction (profile/lead relief) may prevent recurrence on replacement gears.
5. Oil Cleanliness. Institute enhanced filtration checks and debris trending (ferrous density) in parallel with vibration, given the late-stage evidence of debris recirculation.
6. Spare Strategy. Maintain a ready spare gear pair for MG-5025A and pre-approve a swap procedure triggered by the above alert criteria.

Conclusion

From a stable Healthy state in February through 8 April 2023, the MG-5025A gear pair aboard INS *Haifa* entered a progressive tooth-wear regime beginning 9 April and advanced through 35 documented wear cases to a failure on 15 June 2023. The evolution—captured by structured 60 s, 50 kHz vibration recordings at 15 rps and 45 rps and corroborated by tooth-flank imagery—is characteristic of scuffing-initiated pitting growing into macropitting/spall, ultimately producing loud noise, high vibration, and functional loss. The recommended CBM protocol and inspection actions above are expected to detect future onsets earlier, limit progression, and reduce unplanned downtime for this gearbox brand.

Table 1: Wear severities dimensions.

Case	Wear depth [µm]	Case	Wear depth [µm]	Case	Wear depth [µm]	Case	Wear depth [µm]
Healthy	0	W9	276	W18	450	W27	684
W1	40	W10	294	W19	466	W28	720
W2	81	W11	305	W20	488	W29	744
W3	115	W12	323	W21	510	W30	769
W4	159	W13	344	W22	524	W31	797
W5	175	W14	378	W23	557	W32	825
W6	195	W15	400	W24	579	W33	853
W7	227	W16	417	W25	608	W34	890
W8	256	W17	436	W26	637	W35	932

Table 2: Sensors and data acquisition

Sensor	Direction and Position	Brand	Sensitivity [mV/g]	Sampling Rate [kS/sec]
Accelerometer	Gravitational Starboard Shaft	Dytran 3053B 1783	9.47	50
Accelerometer	Gravitational Port Shaft	Dytran 3053B 1787	9.35	50
Tachometer – 30 teeth	Starboard	Honeywell 3010AN	–	50
Tachometer – 30 teeth	Port	Honeywell 3010AN	–	50

Table 3: Transmission features

Feature	Value / Type
Model	MG-5025A
Gears type	Spur
Module	3
Transmission ratio ($z_{driving}/z_{driven}$)	18/35
Lubricant	2640 semi-synthetic (15W/40)

Figure 1: Face view of a gear tooth at all health status

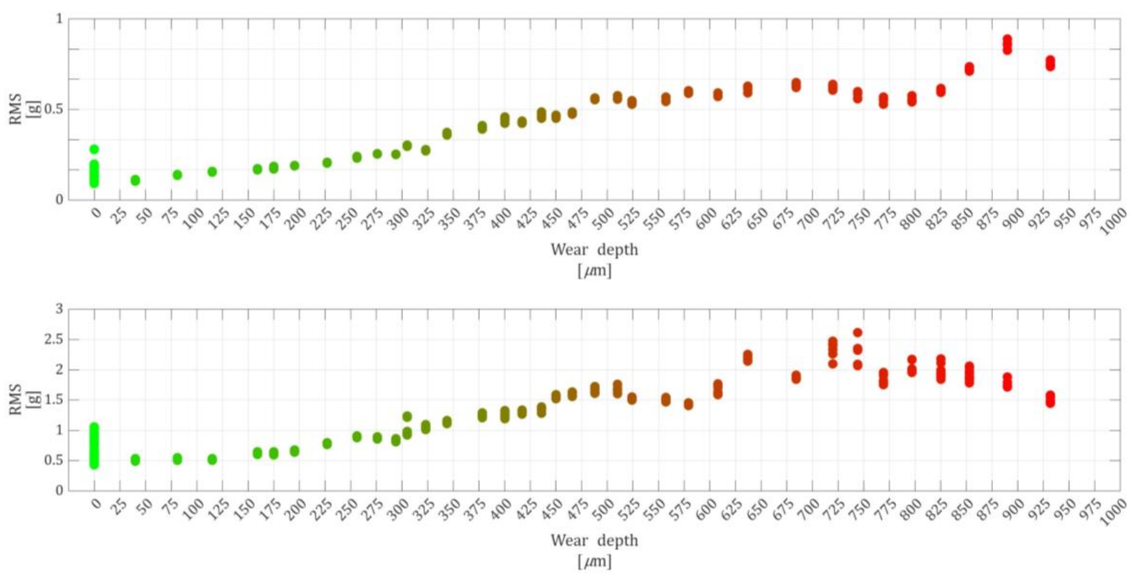

Figure 2: RMS level against wear depth at 15 [RPS] (above) and at 45 [RPS] (below). Healthy records are noted as zero wear depth.

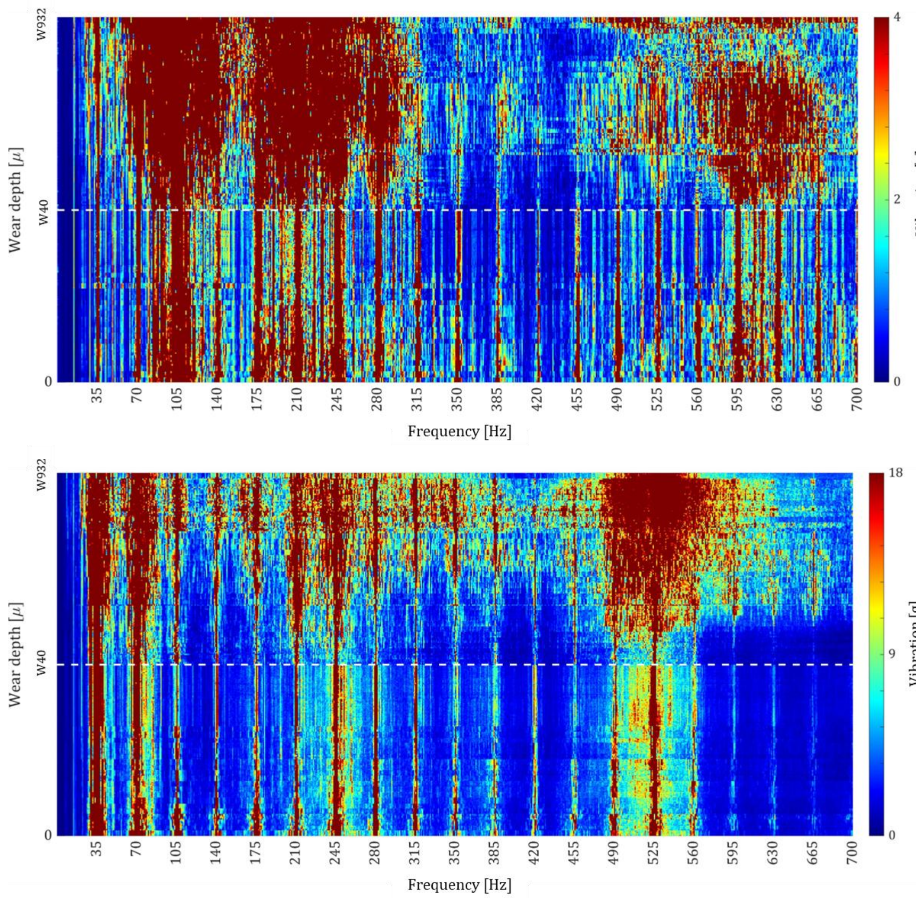

Figure 3: Fast Fourier Transform (FFT) spectrogram at 15 [RPS] (above) and 45 [RPS] (below). GMF harmonics are labeled on the horizontal axis, and the white dashed line marks the separation between healthy and faulty cases.

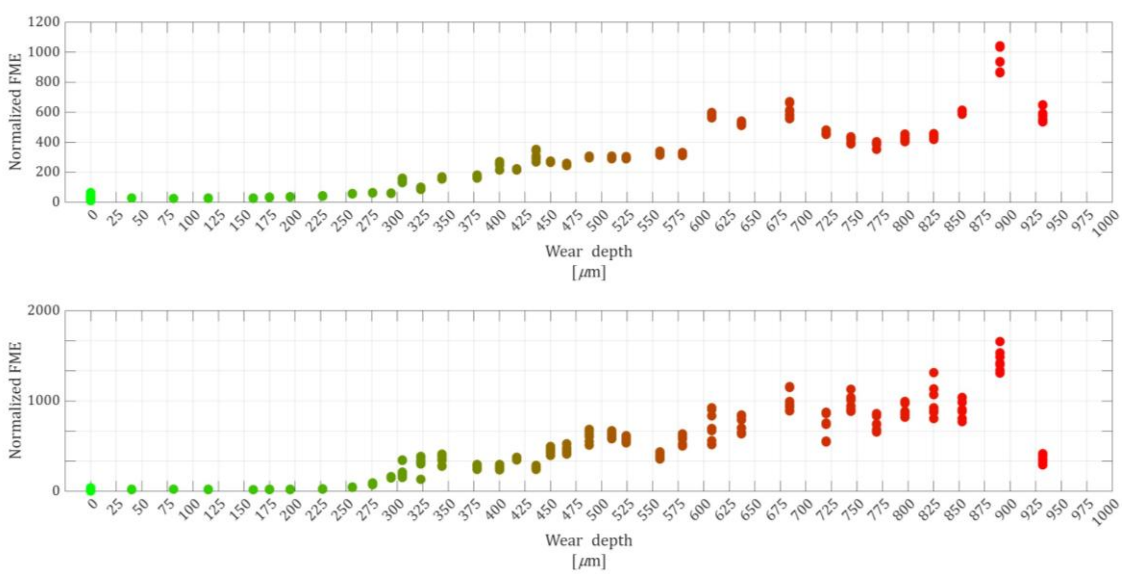

Figure 4: Normalized FME against wear depth at 15 [RPS] (above) and 15 [RPS] (below).