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“DESIGN AND FAILURE PREVENTION OF DRAG CONVEYOR CHAINS FOR BULK-MATERIAL HANDLING: A REVIEW OF FAILURE MODES, CHAIN SELECTION, FINITE ELEMENT ANALYSIS, AND CONCURRENT ENGINEERING”

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ABSTRACT

Drag conveyors are widely used to move bulk materials such as grains, cement, fly ash, and chemical powders through enclosed troughs, and the endless chain that drags the material is the most heavily loaded and most frequently maintained element of the system. Chain failures cause unplanned stoppages, loss of productivity, and safety risks, and they arise from design, material, manufacturing, operating, and environmental causes. This review paper presents an assessment of published work and engineering practice related to the design and selection of drag conveyor chains, with particular emphasis on failure modes, chain components and design standards, chain pull and chain selection, finite element analysis of chain links, and the use of concurrent engineering and life-cycle assessment in product development. Failure investigations of conveyor, crawler, and carrier chains, studies of chain-strip behaviour under tensile loading, wear and dynamic studies of chain drives, and manufacturer design guides are examined. The review indicates that most published work addresses the causes and types of chain failure, whereas fewer studies address the design of the chain itself, and no study dealing with the design of the fasteners that retain the outer link on the pin, or with the environmental impact of the chain, was identified in the sources examined. Research gaps include limited reporting of link thickness selection against chain pull and factor of safety, scarce analysis of pin and fastener assemblies, and limited life-cycle assessment of conveyor chains. The findings are intended to support the development of reliable, economical, and sustainable drag conveyor chains for bulk-material handling.

Key Words: Drag conveyor chain; material handling; chain failure analysis; chain selection; finite element analysis; concurrent engineering; fasteners; life-cycle assessment.

I. INTRODUCTION

Material handling is the movement, protection, storage, and control of materials throughout manufacturing, warehousing, distribution, and disposal, and it is one of the activities that most strongly affects productivity and cost in process industries. Manual handling exposes workers to force, awkward postures, and repetitive motion that can cause injury and wasted effort [1], whereas automated handling equipment reduces material damage and improves working conditions [2]. Conveyors form a large group of handling equipment and include chute, roller, belt, slat, chain, and drag conveyors, and the selection of the equipment depends on the material, the required capacity, the layout, and the cost [3], [4], [5]. Handling equipment that is not matched to the layout or to the storage system wastes investment and reduces productivity [6].

A drag conveyor consists of a drive head, a non-drive tail, and a sequence of trough sections between them. Inside the trough, an endless heavy-duty chain with wide links carrying projections, known as flights, drags a bed of bulk material

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from the feeding end to the discharge end. In horizontal operation, a drag conveyor can carry material over roughly 45–50% of the cross-sectional area of the trough, which makes it an efficient means of moving large volumes. Drag conveyors are used in the cement, food, chemical, power, and steel industries to handle materials such as cement, fly ash, grains, soybean, bleaching powder, soda ash, coke, and sinter dust. The chain is assembled from outer link plates, inner link plates, bushes, pins, fasteners such as a nut and split pin or a circlip, and the flights and gussets welded to the links. The outer links, also known as pin links, carry the tension through the pins, while the inner links, also known as bush links, carry the load through the bushes, and the bush rotates freely on the pin so that the chain can articulate around the sprockets [7], [8]. Large-pitch conveyor chains are preferred for drag conveyors because they cost less, give stronger attachments, and move more material than small-pitch chains.

Drag conveyor chains operate under high tensile load, friction, and sometimes humid, chemical, or abrasive environments, and they may receive impact from the sprocket when the chain is misaligned. Failures such as fracture, cracking, wear, and distortion lead to corrective maintenance and loss of production, and the chain is often attended to only after it has been damaged [9], [10]. Design tools such as finite element analysis, systematic product-development approaches such as concurrent engineering, and environmental assessment by life-cycle methods are available to improve chain design, but their application to drag conveyor chains is not widely reported. This paper reviews the literature on these topics with the aim of identifying good practice in drag conveyor chain design and selection and of highlighting the gaps that remain.

II. PROBLEM IDENTIFICATION

Drag conveyors are among the most efficient media for moving large volumes of bulk material from one place to another, but the chain that drives them works under very severe conditions. The chain is subjected to continuous tensile load from the dragged material, friction against the trough, and occasional shock from the sprocket. In practice, the failures that occur are fracture of the full section, cracking of part of the section, wear, and distortion in the form of bending, elongation, or plastic collapse. These failures are attributed to design defects, raw-material defects, operational defects, defects of the fasteners used in the chain assembly, wrong chain selection, and environmental conditions such as humidity and chemicals [9], [11].

A particular difficulty is that the chain is one of the most neglected components when routine maintenance is carried out. It is normally attended to when it has already been damaged or requires replacement, so the cost of failure includes not only the chain but also the stoppage of the conveying system and the associated loss of production. The selection of the chain is itself a demanding task because it depends on the working load, the conveyor size and length, the material handled, the operating environment, the working hours, and the cost [8], [12]. If the chain thickness or the factor of safety is chosen without reference to the chain pull, the chain may be either overloaded or unnecessarily heavy and costly.

Most of the available research concerns the cause and type of failure of chains. Less work is available on the design of the chain links themselves, and the sources examined here do not report studies on the design of the fasteners used on drag conveyor chains or on the environmental impact of the chain. Consequently, there is a need to consolidate the available knowledge on failure modes, chain selection, numerical analysis, and product-development methods, and to identify the evidence that is missing for the design of chains for flat-bottom drag conveyors.

III. RESEARCH OBJECTIVE

The main objective of this review paper is to critically examine published work and engineering practice related to the design, failure, and selection of drag conveyor chains. The specific research objectives are as follows:

- To review failure modes: Examine the types of failure that occur in conveyor chains, such as misalignment, corrosion, erosion, fretting, impact, overload, galling, and fastener failure, together with their diagnosed causes.
- To examine chain components and standards: Review the function of the links, bush, pin, and fasteners and the dimensional recommendations given by chain standards for large-pitch chains.

- To review chain pull and chain selection: Examine the relations used to estimate the tensile load on the chain and the use of breaking load and factor of safety in selecting the chain.
- To analyze numerical methods: Evaluate the use of finite element analysis for stress and displacement in chain links and in the shape optimization of link plates.
- To assess wear, dynamics, and manufacturing: Review studies of abrasive wear, chain-drive dynamics, and the manufacturing of link plates that influence chain life.
- To review concurrent engineering: Examine the application of concurrent engineering to product development and its relevance to chain design.
- To review environmental assessment: Examine the use of life-cycle assessment and eco-design in engineering products.
- To identify research gaps: Identify limitations in existing studies relevant to the design of drag conveyor chains and their fasteners.

IV. LITERATURE REVIEW

The design and selection of conveyor chains are supported by manufacturer design guides, national standards, and research on failure analysis, stress analysis, wear, and product development. The works reviewed below include design guides and standards and research and thesis work published between 1998 and 2014, grouped by theme to show their relevance to the design of drag conveyor chains.

Chain design guides and standards [7], [8], [12], [13], [14]. The chain guides describe the types of conveyor chain, the function of each component, and the procedure for selecting a chain. Chains are commonly grouped as small-pitch, precision, top, free-flow, power-transmission, and large-pitch conveyor chains, and the large-pitch chain is preferred for drag conveyors. The factors that influence selection include the application environment, the nature and temperature of the conveyed material, the conveyed volume, the length and layout of the conveyor, the chain speed, the pitch and attachments, the working hours, and the lubrication. The Japan Chain Industry Association standard recommends a link thickness of 4.7 mm, a bush outer diameter of 22.2 mm, and a pin diameter of 14 mm for chains of 75–150 mm pitch, whereas the Indian standard IS 6834 recommends a link thickness of 6 mm, a maximum bush diameter of 25 mm, and a maximum pin diameter of 15 mm for a pitch of 102 mm. These differences show that the designer must choose the dimensions against the actual load rather than rely on a single recommendation.

Jagtap (2014) [15], [16] studied the behaviour of roller conveyor chain strips under tensile loading using analytical, experimental, and numerical methods, including strain gauges. The study explained that chain strips are tension members that are also subjected to bending and stress concentration around the holes through which the pins pass, and that the strip must have sufficient strength and ductility to withstand these loads and resist fatigue. Fatigue was reported to start at external cracks of the link and to propagate inward until sudden fracture occurred. The study is relevant to drag conveyor chains because their link plates are loaded in the same manner, and it indicates that the region around the holes governs the strength of the link.

Bošnjak et al. (2013) [17] investigated the failure of crawler chain links of a bucket wheel excavator. Stress-state calculations were combined with visual and metallographic examination, chemical analysis, and tests of mechanical properties. The authors concluded that the breakdowns were caused by manufacturing defects and emphasized the importance of comprehensive quality control of chain links. **Sokolski (2014) [18]** evaluated the resistance of large-size caterpillar chain links of mining machinery to catastrophic failure, localized critical areas using numerical models of the links, and proposed modifications of geometric parameters. Both studies show that link failures can be traced to specific regions and defects, and that numerical modelling is useful for locating them.

Haris (2013) [10] investigated the causes of failure of a conveyor chain system through characterization of the failed components. A weld defect in the form of a crater was found to initiate a crack at the joint between the chain attachment and the outer link plate, and cyclic loading caused fatigue failure. Beach marks and scanning electron

microscopy confirmed fatigue crack propagation, and hardness testing showed different hardness in the weld metal, base metal, and heat-affected zone. The defect was classified as a designing-in defect. This finding is directly relevant to drag conveyor chains, in which flights and gussets are welded to the links. **Slabbert (2001) [19]** reported failure analysis of carrier chain pins, which illustrates the importance of the pin in chain integrity.

Failure modes and root-cause analysis [9], [11]. The Renold troubleshooter lists common failure modes of conveyor chains, namely alignment problems, abrasion, corrosion, erosion, cracking, fatigue, fracture, fretting corrosion, galling, overload, pitting corrosion, and wear, and it gives remedies for each. The general root-cause literature lists misuse, assembly errors, manufacturing defects, improper maintenance, fastener failure, design errors, improper material, improper heat treatment, unforeseen operating conditions, inadequate quality assurance, and inadequate environmental protection among the common causes of failure. Table 4.1 summarizes the principal failure modes of drag conveyor chains and their diagnosed causes.

Table 4.1: Principal failure modes of drag conveyor chains and diagnosed causes

Failure mode	Typical observation	Diagnosed cause
Misalignment	Wear of side plates; rubbing marks on plate edges	Chain run out of line; plate edges rubbing against guide tracks
Corrosion at high temperature	Corroded chain components	Ineffective lubrication at raised temperature
Corrosion and erosion	Severe wear of pin and bush surfaces; thinning of side plates	No lubrication; acidic, caustic, or sand-contaminated environment
Fretting	Scoring and red deposit on pins and bushes	Marginal lubrication allowing asperity contact
Impact	Cracks on bushes; abrasion of inner plate faces	Chain riding on sprocket teeth and dropping into engagement
Overload	Plastic elongation of the bush hole in the inner plate	Severe tensile overload
Galling	Fused pin faces	Lubricant squeezed out under very high pressure
Tensile overload	Outer link failed in tension; fastener failure	Outer link thinner than inner link; overloaded chain

Mwaro (2012) [20] studied grain breakage during conveyance of bulk maize through a drag chain conveyor. Broken grains reduce the weight and storage time of the grain, increase resistance to airflow in storage, create risks of dust explosion and hygiene problems, and lower product quality. This work shows that the performance of the chain affects not only the conveyor but also the product handled, which is important for food-grain applications.

Finite element and manufacturing studies [21], [22], [23]. Patil investigated the application of the fine piercing process to roller chain link plates and reported a 22% increase in the shear-zone length compared with conventional piercing, with finite element predictions of displacement and stress within about 2.5–4.8% of the measured values. The work shows that the manufacturing process of the link plate influences its breaking load. Rai reviewed finite element and double-shear stress analysis of shackle chain links and showed that finite element models can identify the parameters that influence link failure. Bhoite examined the effect of the radius between the connecting holes of the outer link, a dimension that is usually left to the manufacturer, on stress and material saving. These studies support the use of finite element analysis for link-plate design, but they concern roller and shackle chains and not drag conveyor chains.

Wear and dynamics [24], [25], [26]. Van Steenkiste identified two-body contact guidance wear and three-body shackle contact wear as the most important wear mechanisms of link chains operating in abrasive environments. Pedersen developed a formulation based on a continuous contact force method for the dynamic simulation of roller chain drives, including the polygonal effect, roller impact at engagement, link flexibility, and coupling of axial and transverse vibration. Zheng *et al.* used explicit finite element simulation of roller chain drives with clearance between components to study the transient vibration of the engaging rollers, which is important for noise. These studies concern the interaction between chain and sprocket and complement the static analysis of link plates.

Conveyor operation and energy [27], [28]. Hulst modelled a chain conveyor as a queuing network to improve the continuity of operation and found that the algorithm used was not suitable for the chain conveyor because deviations could reach 30% for multiple-server networks and 80% for multi-class networks. Clénet examined the optimization of the energy efficiency of conveyors. These works show that conveyor performance depends on operational factors in addition to chain strength.

Concurrent engineering [29], [30], [31], [32], [33], [34], [35]. Concurrent engineering is a systematic approach to the integrated design of products and their related processes, including manufacturing and support, in which all elements of the product life cycle are considered from the start. Bogus *et al.* showed that overlapping design activities can reduce design delivery time. Ramana reported a positive effect of concurrent engineering on new-product development in Indian two-wheeler companies, and Couchman reported from a survey of 150 Australian manufacturers that 54% used the approach to some extent and that adopters had obtained benefits. Samsudin discussed the integration of design for assembly and quality function deployment, and Gunasekaran proposed a framework for implementing concurrent engineering in process industries. These studies indicate that concurrent engineering is applicable to the development of process-plant equipment, but no application to drag conveyor chains was found in the sources examined.

Eco-design and life-cycle assessment [36], [37], [38]. Johansson identified twenty success factors for the integration of eco-design in product development, grouped into management, customer relationships, supplier relationships, the development process, competence, and motivation. Sharma used life-cycle assessment to evaluate the environmental impact of engine sub-assemblies of a two-wheeler and other consumer products. These works provide methods that can be applied to conveyor chains, but no life-cycle assessment of a drag conveyor chain was found in the sources examined.

Summary of the literature. Several themes emerge from the reviewed work. First, chain failure is caused by a combination of overload, misalignment, lubrication problems, wear, corrosion, and manufacturing or weld defects, and the failure investigations point to the link plates, pins, bushes, and welded attachments as the critical regions [9], [17], [10]. Second, finite element analysis is an established means of locating high-stress regions and of evaluating geometric changes, although most reported applications concern roller, shackle, or crawler chains [22], [23], [18]. Third, chain selection guides give dimensional recommendations that differ between standards, and the choice of link thickness should be justified against chain pull and factor of safety [8], [13], [14]. Fourth, concurrent engineering and life-cycle assessment are well documented in other products but are not reported for drag conveyor chains [29], [37]. The research gaps are therefore the limited reporting of link thickness selection against chain pull and safety factor, the scarcity of analysis of the pin and fastener assembly that retains the outer link, and the lack of environmental assessment of conveyor chains.

V. CONCLUSION

This review examined published work and engineering practice related to the design, failure, and selection of drag conveyor chains for bulk-material handling. The literature indicates that chains fail through overload, misalignment, ineffective lubrication, wear, corrosion, impact, and manufacturing or weld defects, and that the link plates, pins, bushes, and welded attachments are the critical regions. Chain standards and design guides provide dimensional recommendations, but these differ and should be checked against the chain pull and the required factor of safety. Finite element analysis is valuable for evaluating link stress and displacement and for guiding geometric changes, and concurrent engineering and life-cycle assessment provide frameworks for developing economical and sustainable

chains. Few studies address the design of the chain itself, and none was identified for the fasteners that retain the outer link or for the environmental impact of the chain. Future research should combine analytical chain-pull calculation, finite element analysis of links and of pin and fastener assemblies, and life-cycle assessment, and should validate the results experimentally and in service, in order to develop reliable and efficient drag conveyor chains.

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