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WEAKLY $G(X)$-P-CLEAN RINGS

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Abstract Let R be an associative ring with identity and $g(x)$ be a fixed polynomial in $C(R)[x]$. In this paper, we introduce the notion of weakly $g(x)$-p-clean rings where every element r can be written as $r = p + s$ or $r = p - s$, where $p \in Pu(R)$ and s is a root of $g(x)$. We study various properties of weakly $g(x)$-p-clean rings. It is proved that, if R is a ring and $2 \in C(R)$ be unit such that $(2^{-1})^2 = 1$, then R is weakly p-clean and $2 \in Pu(R)$ if and only if R is weakly $(x^2 - 2^{-1}x)$-p-clean if and only if R is weakly $(x^2 + 2^{-1}x)$-p-clean.

1 Introduction

Let us consider an associative ring R with a multiplicative identity. An element $p \in R$ is called as pure if there exists some $q \in R$ such that $p = pq$ [12]. The notation $Pu(R)$ represents the collection of all such pure elements in R. Commonly used subsets in ring theory include $U(R)$, $Id(R)$, and $C(R)$, representing the units, idempotents, and center of the ring, respectively. An element $r \in R$ is called clean if $r = u + e$, where $u \in U(R)$ and $e \in Id(R)$ [1, 13]. These ideas have been further extended in various studies [5, 8, 9, 22] .This notion has been generalized by incorporating polynomial roots. If $g(x) \in C(R)[x]$ is a polynomial, an element $r \in R$ is said to be $g(x)$-clean if it can be written as a sum of a unit and a root of $g(x)$. The ring is termed $g(x)$-clean if every element in R satisfies this property [6, 7]. A more relaxed version, termed weakly $g(x)$-clean, allows r to be either the sum or the difference of a unit and an $g(x)$-root [2]. These ideas have been further extended in various studies [15, 16, 17, 18]. If $e \in Id(R)$ and $p \in Pu(R)$ exist for any $r \in R$ such that $r = p+e$, then the ring R is considered p-clean [10, 11]. A ring R is said to be weakly p-clean, if every $r \in R$ can be written as such that $r = p + e$ or $r = p - e$, where $p \in Pu(R)$ and $e \in Id(R)$ [24]. For a given polynomial $g(x) \in C(R)[x]$, suppose R is a ring. A $g(x)$-p-clean element is considered as an element $r \in R$ if $r = p + s$ such that $p \in Pu(R)$ and $g(s) = 0$. Every element in a ring R must be $g(x)$-p-clean for the ring to be considered $g(x)$-p-clean [19, 20].
In this paper, we introduce and study a more general concept is called weakly $g(x)$-p-clean rings, where each element of R can be written as the sum or difference of a pure element and an $g(x)$-root. The ring R is called weakly $g(x)$-p-clean if each of its elements is weakly $g(x)$-p-clean.This notion encompasses $g(x)$-clean and p-clean structures as exceptional cases. It is shown that, if R and S are two rings, $\phi : R \longrightarrow R'$ is a ring epimorphism and $g(x) = \sum_{i=0}^{n} r_i x^i \in C(R)[x]$. Also, if R is weakly $g(x)$-p-clean, then R' is weakly $g_\phi(x)$-p-clean (Lemma 2.7). It is proved that, if R is a ring and and $2 \in C(R)$ be a unit such that $(2^{-1})^2 = 1$, then R is weakly p-clean and $2 \in Pu(R)$ if and only if R is weakly $(x^2 - 2^{-1}x)$-p-clean if and only if R is weakly $(x^2 + 2^{-1}x)$-p-clean (Corollary 2.15).

2 Main results

In this section, we present the framework for elements and rings that are described as weakly $g(x)$-p-clean. The focus then shifts to analyzing the essential properties that characterize these rings. To support our findings, relevant examples are provided.

Definition 2.1. If there is a with the value $p = pq$, then a component $p \in R$ is considered pure [12]. Assuming that the collection of pure elements in the ring R is represented by $Pu(R)$.

Definition 2.2. When there are $p \in Pu(R)$ and $e \in Id(R)$ so that $r = p + e$, then $r \in R$ is considered a p-clean element. When all elements in a ring R are p-clean, the ring is considered a p-clean ring [10, 11].

Definition 2.3. For a given polynomial $g(x) \in C(R)[x]$, suppose R is a ring. A $g(x)$-p-clean element is considered as an element $r \in R$ if $r = s+p$ such that $p \in Pu(R)$ and $g(s) = 0$. Every element in a ring R must be $g(x)$-p-clean for the ring to be considered $g(x)$-p-clean [19, 20].

Let $R = \mathbb{Z}$ and $g(x) = (x^2 - x) \in C(R)[x]$. Then R is $g(x)$-p-clean [19].
In the following, we define the weakly $g(x)$-p-clean rings, then we study some of the fundamental properties of weakly $g(x)$-p-clean rings. Moreover, we give some necessary examples.

Definition 2.4. Let R be a ring and $g(x)$ be a polynomial in $C(R)[x]$. Then an element $r \in R$ is called weakly $g(x)$-p-clean if there exist $p \in Pu(R)$ and the root s of $g(x)$ such that $r = p + s$ or $r = p - s$. The ring R is said to be weakly $g(x)$-p-clean if every element of R is weakly $g(x)$-p-clean.

It is clear that the $(x^2 - x)$-weakly p-clean rings are precisely the weakly p-clean rings. Obviously, $g(x)$-p-clean rings are weakly $g(x)$-p-clean. Also, if $g(-x) = -g(x)$ or $g(-x) = g(x)$, then the concepts $g(x)$-p-clean and weakly $g(x)$-p-clean coincide. So the interesting case is when $g(x)$ is neither an even nor an odd polynomial. Every $g(x)$-p-clean ring is weakly $g(x)$-p-clean. The following example shows that every weakly $g(x)$-p-clean ring is neither $g(x)$-p-clean nor p-clean ring, in general.

Example 2.5. (1) $\mathbb{Z}$ is weakly $(x^2 - x)$-p-clean which is not $(x^2 - x)$-clean.

(2) $\mathbb{Z}_{(3)} \cap \mathbb{Z}_{(5)} = \{\frac{a}{b} \mid a, b \in \mathbb{Z}, b \neq 0, \gcd(3, b) = 1, \gcd(5, b) = 1\}$ is weakly $(x^2 - x)$-p-clean which is not $(x^2 - x)$-clean.

Proposition 2.6. *Let R be a Boolean ring with more than two elements, and let $r \in R$ be an element not equal to 0 or 1. Then R is not weakly $g(x)$-p-clean, where $g(x) = (x + 1)(x + r)$.*

Proof. R is not $g(x)$-p-clean, since assuming $r = p + s$ or $r = p - s$ for some pure p and root s leads to a contradiction. □

Let R and R' be two rings. Suppose $\phi : C(R) \longrightarrow C(R')$ is a ring homomorphism with $\phi(1_R) = 1_{R'}$. If $g(x) = \sum_{i=0}^{n} r_i x^i \in C(R)[x]$, we let $g_\phi(x) := \sum_{i=0}^{n} \phi(r_i)x^i \in C(R')[x]$.

Lemma 2.7. *Let R and R' be two rings, $\phi : R \longrightarrow R'$ be a ring epimorphism and $g(x) = \sum_{i=0}^{n} r_i x^i \in C(R)[x]$. If R is weakly $g(x)$-p-clean, then R' is weakly $g_\phi(x)$-p-clean.*

Proof. Suppose that $r' \in R'$. Since ϕ is a ring epimorphism, there exists $r \in R$ such that $r' = \phi(r)$. Since R is weakly $g(x)$-p-clean, $r = p + s$ or $r = p - s$ such that $p \in Pu(R)$ and $g(s) = 0$. Hence $r' = \phi(r) = \phi(p) + \phi(s)$ or $r' = \phi(r) = \phi(p) - \phi(s)$. Since $p \in Pu(R)$, there exsits $q \in R$ such that $p = pq$. Hence $\phi(p) = \phi(pq) = \phi(p)\phi(q)$, and so $\phi(p) \in Pu(R')$. Since $g(s) = 0$, $g_\phi(\phi(s)) = 0$. Therefore, R' is weakly $g_\phi(x)$-p-clean. □

Definition 2.8. Let R and R' be two rings so R is weakly $g(x)$-p-clean. If there is an epimorphism $\phi : R \longrightarrow R'$, then R' is a weakly $\overline{g}(x)$-p-clean.

Corollary 2.9. *Let R and R' be two rings. Then the following statements hold.*

(i) Let I be an ideal of a weakly $g(x)$-p-clean ring R. Then R/I is weakly $\overline{g}(x)$-p-clean.

(ii) Let the upper triangular matrix ring $T_n(R)$ be weakly $g(x)$-p-clean. Then R is weakly $\overline{g}(x)$-p-clean.

Proof. (i) Suppose that R is weakly $g(x)$-p-clean. Since $\phi : R \longrightarrow R/I$ is an epimorphism, R/I is weakly $\overline{g}(x)$-p-clean, by Lemma 2.7.
(ii) Let the upper triangular matrix ring $T_n(R)$ is weakly $g(x)$-p-clean. Since there exists an epimorphism $\phi : T_n(R) \longrightarrow R$, R is weakly $\overline{g}(x)$-p-clean, by Lemma 2.7. □

Lemma 2.10. *Let $\{R_i\}_{i=1}^n$ be rings, $R = \prod_{i=1}^n R_i$, and $g(x) \in \mathbb{Z}[x]$. Then R is weakly $g(x)$-p-clean if and only if there exist $1 \leq l \leq n$ such that R_l is weakly $g(x)$-p-clean and R_j is $g(x)$-p-clean for all $j \neq l$.*

Proof. Suppose that $i \in \{1, 2, \cdots, n\}$. Hence, R_i is weakly $g(x)$-p-clean, by Lemma 2.7. Assume that neither R_1 nor R_2 are $g(x)$-p-clean. Hence, there exist $r_1 \in R_1$ and $r_2 \in R_2$ such that r_1 is not a sum of a pure and a root of $g(x)$ and r_2 is not a difference of a pure and a root of $g(x)$. Then $(r_1, r_2) \in R_1 \times R_2$ is not weakly $g(x)$-p-clean, a contradiction.
Conversely, Suppose that there exist $1 \leq l \leq n$ such that R_l is weakly $g(x)$-p-clean. Let R_j be $g(x)$-p-clean for all $j \neq l$. If $r = (r_i) \in R$, then there exist $p_l \in Pu(R)$ and a root s_l of $g(x)$ such that $r_l = p_l + s_l$ or $r_l = p_l - s_l$. If $r_l = p_l + s_l$, then for each $i \neq l$, $r_i = p_i + s_i$ such that $p_i \in Pu(R_i)$ and $g(s_i) = 0$. Then $r = (p_i) + (s_i)$ such that $(p_i) \in Pu(R)$ and $g((s_i)) = 0$. If $r_l = p_l - s_l$, then for each $i \neq l$, $r_i = p_i - s_i$ such that $p_i \in Pu(R_i)$ and $g(s_i) = 0$. Then $r = (p_i) - (s_i)$ such that $(p_i) \in Pu(R)$ and $g((s_i)) = 0$. Therefore, R is weakly $g(x)$-p-clean. □

Let R be a ring with an identity and R' be a ring which is an R-R-bimodule such that $(s_1s_2)r = s_1(s_2r)$, $(s_1r)s_2 = s_1(rs_2)$ and $(rs_1)s_2 = r(s_1s_2)$ hold for all $s_1, s_2 \in R'$ and $r \in R$. The ideal extension of R by R' is defined to be the additive abelian group $I(R, R') = R \oplus R'$ with multiplication $(r, s_1)(r', s_2) = (rr', rs_2 + s_1r' + s_1s_2)$. If $g(x) = (r_0, s_0) + (r_1, s_1)x + \cdots + (r_n, s_n)x^n \in C(I(R, R'))[x]$, then $g_R(x) = r_0 + r_1x + \cdots + r_nx^n \in C(R)[x]$.

Lemma 2.11. *Let R be a ring with identity, and R' be a ring that is an R-R-bimodule. If $I(R, R')$ is weakly $g(x)$-p-clean, then R is weakly $g_R(x)$-p-clean.*

Proof. Suppose that $\phi_R : I(R, R') \longrightarrow R$ by $\phi_R(r, s) = r$. Since ϕ_R is a ring epimorphism, R is weakly $g_R(x)$-p-clean by Lemma 2.7. □

Let R be a ring and $\alpha : R \longrightarrow R$ be a ring endomorphism. The ring $R[[x, \alpha]]$ of skew formal power series over R; that is, all formal power series in x with coefficients from R with multiplication defined by $xr = \alpha(r_x$ for all $r \in R$. It is clear that $R[[x]] = R[[x, 1_R]]$ and $R[[x, \alpha]] \cong I(R, \langle x \rangle)$ where $\langle x \rangle$ is the ideal generated by x.

Proposition 2.12. *Let R be a ring and $\alpha : R \longrightarrow R$ be a ring endomorphism. If $R[[x, \alpha]]$ is weakly $g(x)$-p-clean, then R is weakly $g_\phi(x)$-p-clean such that $\phi : R[[x, \alpha]] \longrightarrow R$ is defined by $\phi(f) = f(0)$.*

Proof. Suppose that the skew formal power series $R[[x, \alpha]]$ over R is weakly $g(x)$-p-clean. Since $\phi : R[[x, \alpha]] \longrightarrow R$ is defined by $\phi(f) = f(0)$, it is an epimorphism, R is weakly $\overline{g}(x)$-p-clean, by Lemma 2.7.

□

Theorem 2.13. *Let R be a ring, k be a positive integer, and $a, b \in R$. Then R is weakly $(ax^k - bx)$-p-clean if and only if R is weakly $(ax^k + bx)$-p-clean.*

Proof. Assume taht R is a weakly $(ax^k - bx)$-p-clean ring and $r \in R$. Hence, $-r = p \pm s$ where $p \in Pu(R)$ and $as^k - bs = 0$. Then $r = (-p) \pm (-s)$ where $-p \in Pu(R)$ and $a(-s)^k + b(-s) = 0$. Therefore, R is weakly $(ax^k + bx)$-p-clean.
Conversely, assume that R is weakly $(ax^k + bx)$-p-clean and $r \in R$. Hence, $-r = p \pm s$, where $p \in Pu(R)$ and $as^k + bs = 0$. Then $r = (-p) \pm (-s)$, where $-p \in Pu(R)$ and $a(-s)^k - bs = 0$. Therefore, R is a weakly $(ax^k - bx)$-p-clean ring. □

Theorem 2.14. *Let R be a ring and $a \in C(R)$ be unit such that $(a^{-1})^2 = 1$.Then R is weakly p-clean and $a \in Pu(R)$ if and only if R is weakly $x(x - a^{-1})$-p-clean.*

Proof. Suppose that R is weakly p-clean and $a \in Pu(R)$. Let $r \in R$. Then $ra = p + e$ or $ra = p - e$ for some $p \in Pu(R)$ and $e \in Id(R)$. Hence $r = pa^{-1} + ea{-}1$ or $r = pa^{-1} - ea^{-1}$. It is clear that $pa^{-1} \in Pu(R)$ and ea^{-1} is a root of $x(x - a^{-1})$. Therefore, R is weakly $x(x - a^{-1})$-p-clean.
Conversely, assume that R is weakly $x(x - a^{-1})$-p-clean. Write $0 = p + s$ or $0 = p - s$ where $p \in Pu(R)$ and $s(s - a^{-1}) = 0$. Hence $s = \pm p \in Pu(R)$ and $s - a^{-1} = 0$, and so $a \in Pu(R)$. Suppose that $r \in R$ and write $ra = p + s$ or $ra = p - s$, where $p \in Pu(R)$ and $s(s - a^{-1}) = 0$. Hence $r = pa^{-1} + sa^{-1}$ or $r = pa^{-1} - sa^{-1}$ such that $pa^{-1} \in Pu(R)$ and

$$(sa^{-1})^2 = s(s - a^{-1} + a^{-1})(a^{-1})^2 = s(s - a^{-1})(a^{-1})^2 + sa^{-1}(a^{-1})^2 = sa^{-1}.$$

Then R is weakly p-clean. □

Corollary 2.15. *Let R be a ring and $2 \in C(R)$ be a unit such that $(2^{-1})^2 = 1$. Then the following statements are equivalent.*

(i) R is weakly p-clean and $2 \in Pu(R)$.

(ii) R is weakly $(x^2 - 2^{-1}x)$-p-clean.

(iii) R is weakly $(x^2 + 2^{-1}x)$-p-clean.

Proof. Follows from Theorems 2.13 and 2.14. □

A Morita context is a 6-tuple $\mathcal{M}(R, M, K, R', \phi, \psi)$, where R and R' are rings, M is an (R, R')-bimodule, K is a (R', R)-bimodule, and $\phi : M \otimes_{R'} K \longrightarrow R$ and $\psi : K \otimes_R M \longrightarrow R'$ are bimodule homomorphisms such that $T(\mathcal{M}) = \begin{pmatrix} R & M \\ K & R' \end{pmatrix}$ is an associative ring with the Obvious matrix operations. The ring $T(\mathcal{M})$ is the Morita context ring associated with $\mathcal{M}$. For more on Morita context rings see [3, 4, 21, 23]. If $g(x) = \begin{pmatrix} r_0 & m_0 \\ k_0 & s_0 \end{pmatrix} + \begin{pmatrix} r_1 & m_1 \\ k_1 & r'_1 \end{pmatrix} x + \cdots + \begin{pmatrix} r_n & m_n \\ k_n & r'_n \end{pmatrix} x^n \in C(T(\mathcal{M}))[x]$, then $g_R(x) = r_0 + r_1x + \cdots + r_nx^n \in C(R)[x]$ and $g_{R'}(x) = rr'_0 + r'_1x + \cdots + r'_nx^n \in C(R')[x]$.

Theorem 2.16. *Let the Morita context ring $T(\mathcal{M}) = \begin{pmatrix} R & M \\ K & R' \end{pmatrix}$ be weakly $g(x)$-p-clean with $\phi, \psi = 0$. Then R is weakly $g_R(x)$-p-clean and R' is weakly $g_{R'}(x)$-p-clean.*

Proof. Suppose that $T(\mathcal{M})$ is weakly $g(x)$-p-clean with $\phi, \psi = 0$. Hence, $I = \begin{pmatrix} 0 & M \\ K & R' \end{pmatrix}$ and $J = \begin{pmatrix} R & M \\ K & 0 \end{pmatrix}$ are two ideals of $T(\mathcal{M})$. Since $T(\mathcal{M})/I \cong R$ and $T(\mathcal{M})/J \cong R'$, the assertion holds by Lemma 2.7. □

Corollary 2.17. *Let R and R' be two rings and M be an (R, R')-bimodule. Let $T = \begin{pmatrix} R & M \\ 0 & R' \end{pmatrix}$ be the formal triangular matrix ring. If T is weakly $g(x)$-p-clean, then R is weakly $g_R(x)$-invo-clean and R' is weakly $g_{R'}(x)$-invo-clean.*

Proof. Follows from Theorem 2.16. □

Corollary 2.18. *Let R be a commutative ring and M be an (R, R)-bimodule such that $2M = 0$. Then $T = \begin{pmatrix} R & M \\ 0 & R \end{pmatrix}$ is weakly $g(x)$-p-clean if and only if R is weakly $g(x)$-p-clean.*

Proof. Follows from Lemma 2.7 and Corollary 2.17. □

We close the article with the following two problems.

Problem 2.19. What is the behaviour of the matrix rings over weakly $g(x)$-p-clean rings?

Problem 2.20. Let R be a weakly $g(x)$-p-clean ring and $e \in Id(R)$. What is the behaviour of the corner ring eRe?

3 Conclusion remarks

In this paper, we introduce and study a more general concept is called weakly $g(x)$-p-clean rings, where each element of R can be written as the sum or difference of a pure element and an $g(x)$-root. The ring R is called weakly $g(x)$-p-clean if each of its elements is weakly $g(x)$-p-clean.This notion encompasses $g(x)$-clean and p-clean structures as exceptional cases. It is shown that, if R and S are two rings, $\phi : R \longrightarrow R'$ is a ring epimorphism and $g(x) = \sum_{i=0}^{n} r_i x^i \in C(R)[x]$. Also, if R is weakly $g(x)$-p-clean, then R' is weakly $g_\phi(x)$-p-clean (Lemma 2.7).

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